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CONTROL TRANSLATION SERIES

Measurement Techniques

(The Soviet Journal *Izmeritel'naia Tekhnika* in English Translation)

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SOVIET INSTRUMENTATION AND CONTROL TRANSLATION SERIES

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The original Russian articles are translated by competent technical personnel. The translations are on a cover-to-cover basis, permitting readers to appraise for themselves the scope, status and importance of the Soviet work.

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All views expressed in the translated material are intended to be those of the original authors, and not those of the translators, nor the Instrument Society of America.

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40 YEARS SINCE THE INTRODUCTION OF THE METRIC SYSTEM IN THE USSR.

40 years have passed since the decree of the Council of Peoples Commissars of September 15th 1918 "on the introduction of the international metric decimal system of weights and measures."

The introduction of the metric system in the USSR was an important progressive measure of the Soviet Government in the first year of its existence.

The metric system, established in France at the end of the 18th century during the Great French Revolution, received international recognition only in the middle of the 19th century.

At an international diplomatic conference on May 20, 1875, 17 states, including Russia, signed an agreement "for ensuring international unification and improvement of the metric system."

This agreement provided for:

1) the establishment of international prototypes of the meter and kilogram, made of an alloy of platinum and iridium; equivalent to the archive meter and kilogram;

2) the setting up of a scientific organization, the International Bureau of Weights and Measures, maintained at the expense of all the countries which had signed the metric convention;

3) the foundation of the International Committee of Weights and Measures consisting of scientists, who represented the various countries, and controlled the activity of the International Bureau of Weights and Measures,

4) the convening once every six years of a general conference on weights and measures for "discussing and adopting the required measures for the dissemination and improvement of the metric system."

The preparation and checking of the reference meters and kilograms made of a platinum-iridium alloy was completed in 1889. The same year the first general conference on weights and measures established international prototypes of the meter and the kilogram and entrusted the International Bureau of Weights and Measures with their preservation. The remaining standards were distributed by drawing lots among the countries which had signed the metric convention.

In the 83 years since the signing of the metric convention the metric system spread and developed. At present 35 countries adhere to the metric convention with a total population of some 1,400 million people.

One of the important events in the dissemination of the metric system was the joining of the metric convention by India in December 1956, and the proposed adoption of the metric system throughout the country within the maximum period of 10 years.

Noting the importance of this legislation the Prime Minister of India Mr Nehru stated in his article in the Journal "Metric Measurements," "one of the greatest reforms which we have undertaken in India is the adoption of the metric system."

The international metrological organizations have achieved considerable success in their work. Since 1875, 10 general conferences on weights and measures were held and important decisions on questions relating to measuring units and standards and other metrological questions were made.

Among the most important decisions of the general conferences on weights and measures were the establishment of international prototypes of the metric system, the determination of the relation between the meter and the cadmium red line wave-length, the adoption of the international temperature scale and the establishment

of a thermodynamic temperature scale with one reference point (the triple water point), the decision to change from international electrical units to absolute units, the establishment of basic units of the international system of units, etc.

At the Sixth General Conference on Weights and Measures in 1921 the metric convention of 1875 was revised and the activity of the international metric system organization was greatly enlarged.

The International Committee of Weights and Measures held 50 sessions since the time of its inauguration. It consists of 18 members, representing metrological and scientific organizations of various countries, who hold a session of the Committee once every two years as a rule.

At its sessions the Committee receives reports of the activity of the International Bureau of Weights and Measures and its laboratories and makes decisions on other metrological questions of an international character.

For preparing resolutions to be submitted to the Committee five consultative committees have been established: a) the electrical; b) thermometric; c) photometric consultative committees and those for determining; d) the meter and e) the second. The consultative committees consist of the most important national metrological organizations of various countries. The International Committee of Weights and Measures has a permanent System ofUnits commission.

The International Bureau of Weights and Measures is located in Sèvres near Paris on territory specially provided for the purpose by France (Breteuil pavilion and laboratory).

The International Bureau has a depository for standards, and various laboratories for work on linear, mass, temperature, electrical and light measurements. These laboratories systematically check the national standards of various countries.

The International Bureau Laboratories determine various metrologically important physical constants (in particular that of gravitation).

In recent years these laboratories have carried out important work of investigating various sources of light for a new determination of the meter in terms of a light wavelength.

The Russian Academy of Sciences played an important part in the consolidation and dissemination of the metric system by raising in the second half of the 19th century the question of convoking the International Commission of Weights and Measures, which led to the adoption of the metric convention and international prototypes of measures.

The Scientific Keeper of the Depot of Standard Weights and Measures,Academician A. Ia. Kupfer took part in the work of the international conference held in 1856 in Britain on adopting uniformity in the systems of weights, measures and coins. A Committee of Weights,Measures and Coins was formed at the Paris International Exhibition in 1867. A Russian physicist Acad. B. S. Iakobi became chairman of the commission for unifying measurements of length and weights. In 1870 a conference was called in Paris, as proposed by the Russian Academy of Sciences, for "drawing the attention of the Governments of various countries to the necessity of establishing prototypes of measures."

The Russian Technical Society, which displayed great interest in the propaganda in favor of the metric system, published in 1867 a draft decree on the adoption of the metric system in Russia.

The great Russian scientist D. I. Mendeleev took the first step towards introducing the metric system in Russian by means of legislation. By the law of June 4, 1899,drafted mainly by Mendeleev,the metric system was admitted as an optional alternative to the national system of weights and measures.

However it was only under Soviet Power that the changeover to the metric system throughout the country took place.

The decree of the Council of Peoples Commissars of September 14, 1918 provided that:

a) all measurements be made according to the international metric system of weights and measures with decimal divisions and extensions;

b) the basic units of the metric system should consist of sample No. 28 of the international meter and

sample No. 12 of the international kilogram, made of an iridium platinum alloy, handed over to Russia by the first International Conference of Weights and Measures held in Paris in 1889 and kept in the Central Chamber of Weights and Measures;

c) all Soviet establishments and organizations should begin, on January 1, 1919, introducing the international metric system;

d) the use of all weights and measures, other than the metric system, be forbidden from January 1, 1924.

Other items of this decree provided for practical measures to implement the introduction of the metric system.

The Peoples Commisar for Education was instructed to acquaint all school pupils with the metric system, in its widest theoretical and practical applications, and to popularize it in the nation in general.

The decree provided 5 years for the completion of all preparatory work for introducing the metric system all over the country. Yet 2 years before the expiry of the time limit it became obvious that it would be impossible to implement the decree, and the Council of Peoples Commissars extended the limit for another 3 years to January 1, 1927 by its decree of May 29, 1922.

The implementation of the program, which was briefly outlined in the decree of September 14, 1918 and developed later in a detailed plan, approved by the Council of Labor and Defense on October 19, 1923, was entrusted to the Central Metric Commission, which at first reported to the Commissariat of Trade and Industry and later to the Council of Labor and Defense.

In the early years of its work the Central Metric Commission concentrated its attention on introducing into common use the ordinary metric measures, such as weights, measures of length and volume. For this purpose the simplest types of instruments had to be designed and technical instructions issued to the factories and workshops which were making and distributing measuring equipment.

At first it was decided to alter the old Russian measures and instruments into metric ones. This decision speeded up the introduction of the metric system. When the production of metric measures was organized, this temporary step was abrogated (January 9, 1925).

In order to popularize the metric system, simple diagrams of instruments, conversion tables for Russian into metric measures, technical instructions, etc. were published. The Central Chamber of Weights and Measures issued in 1923 a "Table for mutual conversion of Russian and metric measures" calculated with metrological precision. Many papers, pamphlets, articles dealing with the metric system, were written in the languages of the various peoples of the USSR including 30 publications of the Central Chamber of Weights and Measures.

In order to introduce the metric system in all the spheres of national economy the Central Metric Commission published binding instructions for measuring water, in liters, and gas in cubic meters, for introducing the metric system in the wine and spirits industry, including the levying of excise duties for specifying the area of buildings and apartments in metric measures; for uniform abbreviations of metric notations in print, and for the establishment of basic metric measures in industry, trade and transport.

The Council of Peoples Commissars of the USSR examined, in March 1928, the report of the activities of the Central Metric Commission. In its resolution the Council of Peoples Commissars of the USSR stated that the metric system is being generally accepted in various spheres of national economy and the social and cultural life of the country, and that its adoption has made a considerable saving in labor and facilitated the rationalization of national economy.

In the same decree, summing up the work of the Commission, the Council of Peoples Commissars approved the work of the commission, and entrusted it to establish, in conjunction with the Government departments concerned, a three-year plan for the final consolidation of the metric system in the USSR and for the necessary steps to implement the plan; the Council of Peoples Commissars also obliged the State establishments and organizations and the cooperative and public organizations to implement the plan, and wound up the work of the Metric Commission on October 1, 1928.

The successes of the USSR in introducing the metric system in such a short time aroused great interest at the seventh General Conference of Weights and Measures (1927). A member of the Soviet delegation Prof. A. N.

Dobrokhotov read two extensive papers at the Conference entitled: "Introduction of the metric system in the USSR" and "Legislation on weights and measures in the USSR for the period of time from 1921 to 1927."

In the years 1931-1934 a system of State standards for measuring units was worked out in the USSR.

A most important development of the metric system was the adoption in 1956 by the International Committee of Weights and Measures, of an international system of units based on six fundamental units (meter, kilogram, second, ampere, degree Kelvin and candle power).

In 1955-1958 the USSR revised its State standards according to the system of units adopted by the International Committee of Weights and Measures.

The metric reform was successfully carried out in our country in a very short time. The adoption of a completely uniform system of measures and the conversion of all types of measurements to the most up-to-date metric units with a decimal system of counting played an important part in the development of science, technology and the entire national economy of the USSR.

DIPLOMAS OF THE ALL-UNION INDUSTRIAL EXHIBITION AWARDED TO MEMBERS OF THE COMMITTEE'S INSTITUTES

P. P. Arapov

The Central Committee of the All-Union Industrial Exhibition made several awards to members of Institutes of the Committee of Standards, Measures and Measuring Instruments who partipated in the 1957 exhibition.

First Degree Diplomas were awarded to Prof. M. F. Romanova Canditate of Tech. Sci. E. D. Volkova Candidate of Tech. Sci., A. I. Kartashev and V. S. Stepanov members of the staff of the D. I. Mendeleev All-Union Scientific Research Institute of Metrology (VNIIM) for the design and development of a universal interferometer for measuring block gauges and quartz geodesical rods by the absolute interference method.

The design of the instrument is based on the combination of a multi-beam and double-beam interferometer. The interferometer has an optical system which serves to produce and observe two systems of interference fringes; a mechanical system for the setting and adjustment of the position of the gauge under test with respect to the mirror; a thermometric system for measuring the difference of temperature between the gauge under test and the tubular standard; a measuring system for adjusting the optical length of the tubular standard and making the achromatic fringes of both interference systems coincide. The optical system together with the gauge under test is placed in a thermostatically controlled chamber. The measurement of the gauge consists in comparing it with the optical length of the tubular standard magnified $\underline{n}$ times by observing superimposed interference fringes in white light. Having determined the length of the tubular standard by means of equal slope rings in monochromatic light of cadmium or krypton and having multiplied it by $\underline{n}$ the length of the tested block gauge is obtained.

The limits of measurement are 100-1,200 mm, and the error of measurement does not exceed ± 0.0001 mm in 1 m. The use of this instrument in measuring practice has solved the problem of measuring precision gauge blocks and quartz rods of large sizes.

Second Degree Diplomas were awarded to members of the staff of the VNIIM Candidates of Tech. Sci. A. D. Veisbrut and B. A. Kamochkin for developing the design of a standard small interval timer DMPV-1 for checking millisecond meters and chronometers (chronographs) with a contact or pulse system of control. The timer provides time intervals from 0.1m sec to 10 sec.

The operation of the timer is based on a digital computer which counts a preset number of cycles of a

known and highly stable frequency (10 kc). When the timer works with a standard oscillator the variation in the time interval of 9.9999 sec produced by it does not exceed 3-4 sec. The accuracy of the time intervals produced by the timer is determined by the relative error of the crystal oscillator frequency (in the case of its own oscillator $\pm 3 \cdot 10^{-5}$) and the permissible absolute error in the signal delay (of the order of a few microseconds). Timer DMPV-1 provides checking of almost all types of instruments for measuring small time intervals.

The instrument was shown at the World Exhibition in Brussels in 1958.

Members of the staff of the All-Union Scientific Research Institute of the Committee (VNIIK) Candidates of Tech. Sci. V. N. Gramenitskii and K. I. Khansuvarov were awarded Second Degree Diplomas for developing the design of a low pressure manometer which was also shown at the Brussels International Exhibition.

The instrument serves for checking standard elastic type high pressure gauges grade 0.2 and standard elastic type low pressure gauges grade 0.2 and 0.35. The instrument consists of two interconnected piston towers with a simple and a differential piston, an oil press and a separating vessel to which the high or low pressure under test is applied.

When high pressure is measured weights are placed on the differential piston pan until the piston assumes its original position. The pressure thus established is measured as the quotient of the weight over the effective area of the piston.

When low pressure is measured weights are placed on the simple piston pan, and pressure is measured as the quotient of the weight over the effective area of the simple piston, multiplied by the ratio of the effective areas of the differential piston. The limits of the high pressure measurements are 0-2.5 kg/cm^2 and low pressure 0-760 mm Hg. The error of measurements does not exceed $\pm$ 0.05% of the measured value.

The head of the Novosibirsk State Institute of Measures and Measuring Instruments A. L. Grokhol'skii was awarded a Second Degree Diploma for establishing a standard set of capacitors and inductors for checking Q meters type KV-1 and UK-1 with respect to all their parameters and for checking equipment which measures impedances in the range of 50 to 60 Mc. The set consists of 8 coils and 4 capacitors. The coils are in hermetically sealed screens, this ensures a stable Q factor. The capacitors have nominal values of 200, 100, 50 and 20 $\mu\mu$f. The production of standard inductances and capacitors provided for the first time in the USSR the possibility of checking Q meters.

Member of the staff of the VNIIK Candidate of Tech. Sci. A. I. Petrov was awarded a Third Degree Diploma for developing a portable instrument PPR-1 for checking differential manometer – consumption meters and other instruments measuring excessive pressure up to 1,000 mm Hg. The error of measurement of these instruments does not exceed $\pm$ 0.3% of the measured value. The use of these instruments for the first time provided the possibility of checking differential manometers – consumption meter on the spot and with greater accuracy than with the present standard equipment.

PRESSING TASKS OF THE ADMINISTRATIVE INSPECTION AGENCIES

B. N. Vorontsov

It is impossible completely to improve industrial administration without reorganizing technical control, which is an inseparable part of the general technological production process. The greater the skill of production, the more exacting become the requirements set for components, the more perfect must the measurement techniques become and the better must the technical inspection be, so as to provide a speedy and high quality inspection of production in the course of manufacture. The system of technical inspection has been ripe for reorganization for a long time, industry itself should be entrusted with production inspection, the administrative inspection agencies retaining only the most important spheres of inspection and the general supervision and organization of technical inspection and control of the measuring equipment.

In many instances the transfer of inspection to the production personnel resulted in the lowering of the quality of production which is explained by the lack of appreciation of the necessity to plan technological production processes and the lack of incentive offered to the personnel concerned. One of the most important conditions for the successful transfer of the inspection functions to the industrial establishments is the training of personnel immediately concerned in the production and inspection of the commodities. The operative, setter, foreman, technician, they are all production workers without whose participation it is impossible to improve the technology of production. Only when the entire production personnel becomes concerned in keeping up the quality of production and learning the correct use of measuring, will the quality of production be ensured.

Measuring laboratories should be drawn into technical inspection, since technical requirements imposed on the quality of production are at times so strict and varied that without special metrological knowledge it is difficult to select the correct measuring methods.

All the problems arising in connection with production measurements should be decided by the head of the department (shop) in conjunction with the appropriate measurement laboratory. As the number of inspection operations transferred to the production personnel increases so will the importance of the measurement laboratories in guiding this work rise and require an increasingly better qualified personnel.

Thus, the Central Measuring Laboratories charged with the supervision of linear and angular measurements must become responsible for all problems of linear and angular measurements in the factory.

At present these laboratories do not receive any concrete instructions from the factory management, and are in fact auxiliary branches of the administrative inspection agencies. This is bound to have a negative effect on the standard of measurements in the plant despite the good organization of the inspection of measuring equipment.

It is insufficient to check the gauges without taking an interest in the manner in which they are being used and in the quality of the products measured with them. Factory inspection loses its purpose if its main objective of making the final product conform to standards is taken out of the hands of the central measuring laboratory. A combination of supervision of the measuring equipment and the quality of production inspection will bring the inspection personnel closer to the actual production, enabling it to determine in good time whether the measuring equipment is being used correctly, to fix suitable periods for checking instruments, to discover and remove the reasons for premature wearing out of the instruments, to eliminate unnecessary calibration before the instrument has passed inspection and above all raise the Central Measuring Laboratory's influence over the general level of industrial measurement technique. An active participation of the Central Measuring Laboratories in the general technology of production will require a raising of their technical competence and supplementing by personnel who will be not only capable of working with measuring instruments, but will initiate new, more advanced methods of inspection and will constantly improve and simplify the administrative inspection methods. The reorganization of industrial administration will oblige the administrative inspection agencies to find new control and inspection methods which at a lower expenditure would provide a higher level of technical measurements in the factories, eliminating any scrap due to defects in the measuring equipment or technique.

In this connection one should consider the role of the Sovnarkhoz in organizing and directing the work of the administrative inspection agencies and in improving the technical inspection organization at the plants.

The necessity of controlling and guiding the work of the administrative inspection agencies by the Sovnarkhoz* is confirmed by the fact that although the central measuring laboratories of plants carry out essentially the same work in checking measuring equipment they are not operating under the same conditions and therefore have not the same opportunities for developing their work. The task of the Sovnarkhoz consists in determining precisely the role of the administrative inspection agencies at the plants, in directing their work to the solution of the basic problems in raising the quality and lowering the cost of production and in bringing the inspection personnel closer to production by means of advanced methods of inspection and by simplifying the inspection procedures. Without the organizing work of the Sovnarkhozes it is impossible to improve the work of the measurement laboratories. The Sovnarkhozes must adopt a number of organizational and technical measures directed to the strengthening and enlarging of the role of the measurement laboratories.

In the first place it is necessary to revise the regulation concerning administrative inspection, having thoroughly discussed it beforehand with the workers in the plants. In working out the regulations, the new

*Council of National Economy.

conditions which have arisen as the result of the reorganization of industrial management and the elimination of administrative barriers should be taken into account.

With the establishment of the Sovnarkhozes a real possibility of reorganizing administrative inspection agencies has presented itself. In the Gor'kii Region central laboratories have been set up in the districts where there were no State Inspection Laboratories. On the iniative of the Gor'kii laboratory and according to the decision of the Gor'kii Sovnarkhoz two central laboratories were set up in Vyksa, for servicing all the industrial plants of the district. The setting up of these laboratories has led to considerable economies and improvements in the inspection and repair of instruments.

The elimination of administrative barriers permitted those plants which had any surplus measuring equipment to pass it on to those which were in need of it.

The leading role of the Sovnarkhozes in strengthening and widening the functions of the administrative inspection agencies will at the same time provide the possibility of organizing technical inspection on new lines making the worker himself the best inspector of the quality of production. In view of the close connection between the quality of production and the work of the administrative inspection agencies it is necessary to reorganize the work of the measuring laboratories in such a way that all their testing, research and organizational work is directed towards increasing the quality and reducing the cost of production. The basic and the most labor-consuming work of the central measuring laboratories in engineering plants is the checking of gauges and it is still unsatisfactory in many respects, thus lowering the efficiency of inspection. In the first place it must be admitted that the instrument inspection times fixed by the central measuring laboratories cannot completely ensure the reliability and accuracy of instruments between the inspections, no matter how often they are carried out. Much depends on the conscientiousness and experience of the people using the instruments, on the vigilance and strictness of the measuring instrument storekeepers, etc.

Thus, for instance, such a widely used tool as a micrometer is checked less than once a month (usually every 2-3 months). During this time it passes through the hands of several more or less qualified workers under different production conditions, and although on returning it to the store it is visually inspected and checked for zero there is no guarantee that it reaches second or third hands in good working order. Moreover in the second and third shifts when the central measurement laboratory inspectors do not work, it is possible that a large proportion of the instruments will not be checked and will be handed out in a faulty condition. The same applies to the checking of special instruments (gauges and various devices). Even in mass production where the wear of gauges is well-known it often happens that a gauge becomes defective long before the regular inspection time. This happens when a new item of production is being "assimilated" and the components are carefully and repeatedly measured. Such and similar cases oblige the administrative inspection agencies to organize their work so as to make the people using the instruments responsible for their conditions. The supervision of the condition of gauges between the regular testing times should be entrusted to the foremen whose duties include the inspection of the quality of production. They should have at their disposal simple means of checking gauges on the spot (a set of three end gauges for checking snap gauges used in mass production, "standards" for setting zeros in instruments and the working part of scales, etc.) The improvement of the condition of universal measuring instruments used in production and their increased life depends directly on the work of the instrument stores and the requirements set when the instruments are returned to the stores.

In searching for the most economical methods of maintaining measuring instruments some of the Gor'kii plants have by way of an experiment assigned instrument to individual workers, granting them the right to determine when their instruments should be checked. Such a right is only granted to the best workers on orders of the foreman and the head of the department after training in the use and safe-keeping of the instrument. The central measuring laboratories reserve the right of spot checks of "personal" instruments on the spot. If the instrument is found to be defective or inaccurate the worker is deprived of the right of exclusive use by order of the head of the department. The new method of using instruments has so far been extended to 350 workers with a total of some 1,200 instruments. After four months' trial this scheme was found to be very satisfactory. Whereas in the course of the usual periodic quarterly inspection of instruments some 15-20% were found defective and had to be sent away for repairs, under the new scheme out of the 1,200 instruments tested only slightly over 1% were found defective. This shows how the new method improves the condition of the instruments when the workers themselves became interested in maintaining them. The plants have thus saved a considerable sum of money due to a fall in the quantity of instrument repairs and a decrease in the inspection work involved. The main aim has also been achieved, the care of instruments and the efficiency of measurements had been improved.

A serious brake on the development and improvement of the checking of measuring instruments is the formal requirements set for their inspection, requirements which do not take into account the production conditions. It is impossible to set the same requirements for instruments used under completely different conditions. Thus, dial gauges, used extensively in mass production, are often rejected owing to the total error of deflection amounting to 10 revolutions of the pointer. However, this total error would not affect the working part of the scale in which only one half of the pointer revolution is used. A dial gauge working with a transmitting lever, which has passed specification tests, can give wrong readings under working conditions where the arms of the lever are made unequal. Similar widespread cases show that inspection methods must be set to agree with the production conditions and in individual cases the specified requirements should be altered or extended with respect to certain parameters of the instrument, providing such changes do not lower the quality of measurement but prolong the life of the instrument. Such a selective approach will save money, prolong the life of instruments and increase the efficiency of testing.

An important role in the correct organization of administrative inspection is played by the supply of instruments to the plants and a correct distribution of instruments between the shops. Often the shelves of shop instrument stores are filled with new instruments not required for this shop and received from the central store as "ballast," whereas another shop may be badly in need of the instruments. Often new details of measuring instruments are produced below the required quality and valuable instruments are rejected due to constructional defects. The continuously improving production methods and introduction of highly productive automatic control devices will require special "standards" for checking them and a constant temperature in the central measuring laboratories. To date there are only very few central measuring laboratories with air conditioning, whereas the need for such laboratories is very great indeed.

The Sovnarkhozes must pay special attention to the selection and strengthening of the personnel of measuring laboratories and the improvement of their qualifications. The Gor'kii Sovnarkhoz in conjunction with the State Control Laboratory has organized courses for 12 plants of the region, for training administrative inspection personnel in optico-mechanical measurements; it is necessary to organize courses for adjusters of measuring instruments. In addition the State Control Laboratories should organize symstematic short seminars on various aspects of measurements, technical conferences for the exchange of experiences with demonstrations of the best measuring instruments and most up-to-date methods of work.

A skilled guidance of the work of administrative inspection agencies by the Sovnarkhozes in conjunction with the State Control Laboratories, working in close collaboration with industrial plants, will raise the role of measuring laboratories which will become centers of organization for all problems of technical measurements from the standard to the final product.

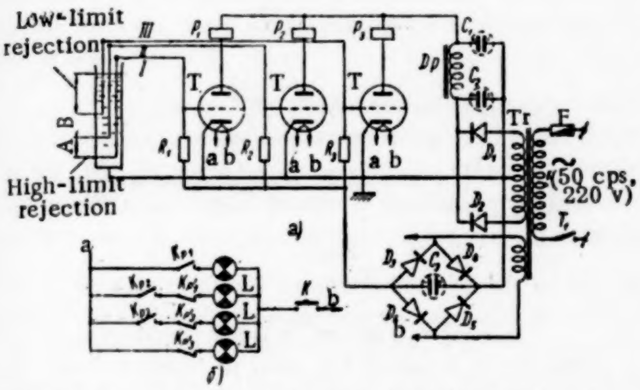
From the Editorial Board. B. N. Vorontsov deals with certain important problems of considerable interest. The editorial board invites readers to express their opinion on the proposals made by the author.

LINEAR MEASUREMENTS

ELECTRIFICATION OF A PNEUMATIC MICROMETER WITH A LIQUID MANOMETER

B. D. Kostrov and S. P. Iudin

Pneumatic micrometers operating with 500–1,000 mm water column manometers are widely used owing to their simplicity of construction, reliability and high sensitivity. However, for automatic control of production, rejection testing, group sorting, machine tool adjustments, etc, they are seldom used. It is difficult to use the manometer water column for closing electrical contacts and transmitting control signals. When current is passed through the water there arises electrolytic action which speedily corrodes the electrical contacts, pollutes the solution and decreases conductivity. The use of mercury instead of water decreases the sensitivity of the instrument and raises its cost in addition to all the difficulties connected with the use of mercury under shop production conditions.



In the Gor'kii Polytechnical Institute the authors have electrified a manometric pneumatic micrometer which used a 1.5% solution of sodium bicarbonate. Owing to the minute currents used and a polarity of connection in which the reducing agent, hydrogen, is produced on the small surfaces of conductors, the harmful electrolytic action was eliminated.

The electrical circuit of the instrument (see figure) consists of four parts: the transducer, amplifier, supply circuit a and the signaling circuit b.

The transducer serves to convert the displacements of the liquid column into electrical signals. Three insulated conductors PEVShO-0.12 with stripped ends and paraffined insulation are lowered into the manometer glass tube. The wire ends are placed according to the levels the liquid takes up for certain dimensions of the measured components. The body of the instrument and the ends of wires serve as the contacts of the electrical circuit which is made through the liquid column.

The circuit contains three similar electronic amplifiers. Let us examine the operation of one of them working with tube T_3 (6Zh4). An electromagnetic relay P_3 type RKN is connected in the anode circuit of this tube. A negative bias, which completely cuts-off the tube, is fed to the grid of the tube through resistor $R_3 = 1$ meg. During testing the relatively low resistance of the transducer's water column is connected between the grid and cathode. When the water column touches conductor III the negative bias of the grid is decreased, tube T_3 conducts and relay P_3 operates. When the contact between them is broken the relay is again released.

The instrument is fed from the ac supplies through a power transformer. The anode voltage is obtained by means of a normal full wave rectifier consisting of diodes D_1 and D_2 (type DGTs-27) and a filter made up of a choke coil and capacitors C_1 and C_2. The heater winding is used to supply the rectifier which provides the negative grid bias and consists of diodes D_3, D_4, D_5 and D_6 (type DGTs-7) and capacitor C_3.

The signalling device consists of four signalling lamps L_4, L_5, L_6 and L_7 relay contacts K_{p2}, K_{p3}, $K_{p'1}$, $K_{p'2}$ and $K_{p'3}$ and a "signal release" push button key K.

The lighting of lamp L_4 denotes rejection of the component at the higher limit, lighting of lamp L_5 denotes that the detail is in group A, that of L_6 that it is in group B and that of L_7 denotes its rejection at the lower limit.

At the highest level of the liquid all the relays are operated, as it is shown in the figure and their contacts provide for the operation of lamp L_7.

In this circuit the signals are only used for automatic control of production.

A PROFILE-TESTING ATTACHMENT FOR THE MII-4 INTERFEROMETER

A. I. Kartashev

The proposed attachment to interferometer MII-4 (Fig. 1) is designed for micro-profile testing of various surfaces by means of scanning them with a diamond needle and recording the needle movement by the variations of the interference pattern. Its advantage consists in the possibility of obtaining interference patterns corresponding to micro-profiles of a studied surface, whose interference pattern cannot be obtained directly on the interferometer owing to the uneven distribution of discrete micro-irregularities (for instance frosted glass surfaces, those with tangled hatching, etched metal surfaces, etc.).

Fig. 1.

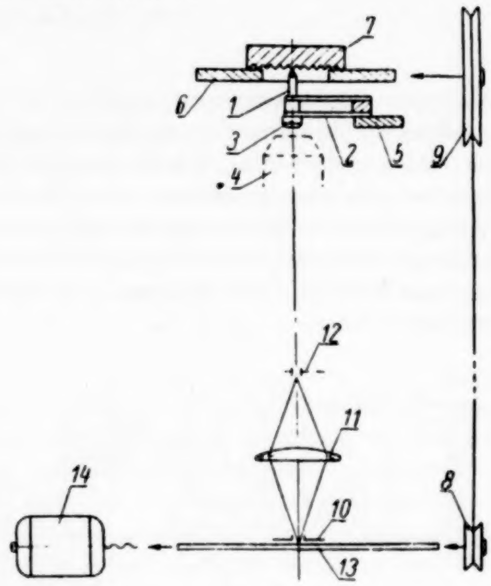


Fig. 2.

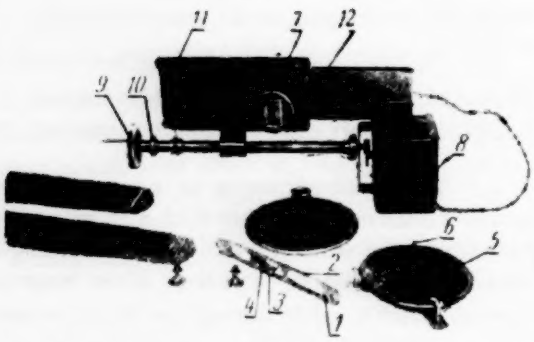


Fig. 3. 1) Bridge; 2) needle; 3) mirror; 4) suspension; 5) surface plate; 6) set screws; 7) cylindrical lense and holder; 8) synchronous motor in casing; 9) handle for manual displacement of the plate holder; 10) small pulleys; 11) plate holder carriage with a nut; 12) carriage slides.

In using this device it is not necessary to calibrate it in advance in order to determine the scale of vertical magnification, since the scale is determined by the interference pattern the distance between the interference maxima for a given wavelength of the monochromatic light used. This constitutes a decisive advantage as compared with the existing systems of optico-mechanical and electro-mechanical profile testing.

The device consists of three main units: the feeler probe, moving plate holder and a motor drive, which are mounted on the interferometer MII-4 without changing its construction.

The feeler probe (Fig. 2) is mounted on a micrometer surface plate and provides profile testing in one selected direction over a distance of 1 to 3 mm.

A diamond, agate or steel needle is fixed in its holder by means of a threaded connection 1 on a flat spring suspension 2, at whose bottom surface opposite the needle a flat mirror 3 is mounted in line with the interferometer objective 4. The suspension is fixed by means of bridge 5 to the stationary part of the surface plate. Cover plate 6 which has a flat upper surface is fixed to the moving part of the surface plate and serves for carrying the object under investigation. When the moving part of the surface plate is displaced, together with the sample, over the needle it conveys to the needle a vertical movement corresponding to the character of the micro-irregularities of the sample surface. Obviously, mirror 3 will follow the needle's movements which will then be recorded by the variations of the interference pattern, i.e., by the displacement of interference lines seen in the microscope's field of vision.

A device with a moving plate-holder which is fixed instead of the photographic camera serves to record the variations of the interference pattern with the movement of the sample. The plate holder is displaced by 100 mm and the plate has the dimensions of 24 x 110 mm so that a standard film can be used. The ratio of the surface plate movement to that of the plate holder can be made according to the nature of the studied surface 1:80, 1:50 or 1:20 by selecting pulleys 8 and 9 of different diameters. The movement from the plate holder drive is transmitted to the surface plate by means of pulley 8, mounted on the worm gear drive, and pulley 9, fixed to the handle of the micrometer movement of the surface plate.

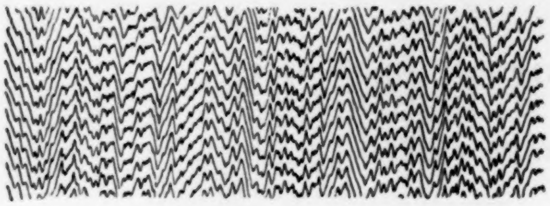


Fig. 4.

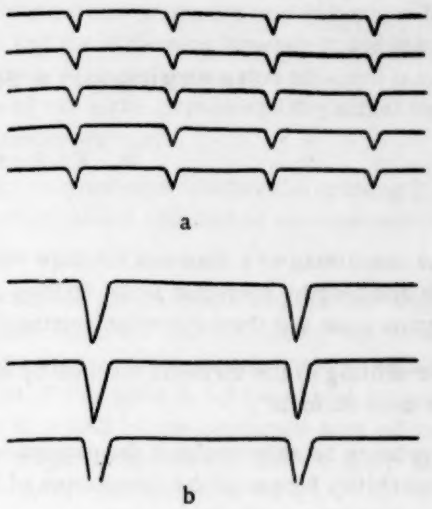


Fig. 5.

The plate holder is moved by the synchronous motor 14 working off the 127 v supply.

So as to obtain a sharp interference pattern a vertical fixed slit 10, 1.5 mm wide and a cylindrical lens 11 are placed in front of the plate, and project the image obtained in the iris diaphragm of the system's output onto the plane of the photographic plate emulsion layer 13.

Figure 3 shows the components of the device. Due to the elasticity of the suspension springs (0,06 mm thick) the needle exerts a very small pressure on the surface under test. By adjusting surface plate 5 by means of three set screws 6 and three tightening screws it is possible to make the end of the needle to protrude such a small amount over the level of the surface plate that when samples of soft materials are tested there remain no noticeable traces on their surfaces.

In order to obtain an interference profile pattern of a sample surface the latter is placed on the surface plate and the needle brought into contact with its surface. Then by focusing the microscope the interference pattern is produced in the field of vision and the lines are placed horizontally; it should be ascertained that the lines do not go out of the field of vision when the surface plate is moved over the whole of its travel. If they do go out of sight the width of the lines should be made narrower, or the cover plate placed parallel with the slides of the surface plate. Next the image is switched to the photographic attachment, the plate holder is opened and the motor switched on. The mechanical system of the device is calculated to complete the profile testing in about 6 minutes.

Different surfaces were tested by means of this attachment. Interference patterns of surfaces with tangled hatching due to the finishing process are of special interest. It is known, for instance, that it is impossible to obtain by means of an interferometer an interference pattern of a polished glass surface. The application of the profile testing attachment overcomes this difficulty and the interference pattern obtained by means of it is easily decipherable.

Figure 4 shows an interference pattern of a ground surface of a glass plate which is used as reference in profile testers type PCh-2. The surface was scanned by means of a diamond needle with a radius of curvature of about 10 μ and profile testing travel of 2 mm. It will be readily appreciated that from such an interference pattern values of H_{cp}, H_{ck} and H_{ca} can be easily calculated.

The values of H_{ck} calculated from such an interference pattern and those obtained by direct reading from the scale of a profile tester type PCh-2, calibrated for this limit of measurement by a regular profile, agreed within 5 %.

In order to check distortions produced in profile-testing by means of a needle with a radius of curvature of finite dimensions, interference patterns of surfaces with a regular profile (Fig. 5a) obtained with a needle were compared with photographs of interference lines of the same surface obtained directly from a MII-4 interferometer (Fig. 5b).

The photographs show a correspondence of both patterns and also the degree of distortions introduced by the profile-testing needle.

SUMMARY

In recording the absolute displacement of the needle, above attachment provides the possibility of studying the nature of the effective profile, to which in fact the profile testing instruments respond, and of determining the values of parameters H_{ck} and H_{ca} to which their indications will correspond according to the radius curvature of the needle, the pressure it exerts on the surface, and the material of which the needle and the sample are made.

INSTRUMENTS FOR CHECKING DIAMOND DIES

V. E. Kostin and M. K. Kovalev

The machining of a diamond die draw channel is a complicated and labor-consuming process. The most important and lengthy operation is the drilling of the basic portions of the draw channel: the lubrication cone, the operation cone and the calibration portion (Fig. 1).

The drilling of the diamond is made by means of conical needles shaped to various angles giving a smooth transition from 90 to 10°.

In order to be able to check the parameters of the draw channel and the drilling needles during boring the Interchangeability Bureau of the Committee of Standards, Measures and Measuring Instruments has developed special opticomechanical instruments.

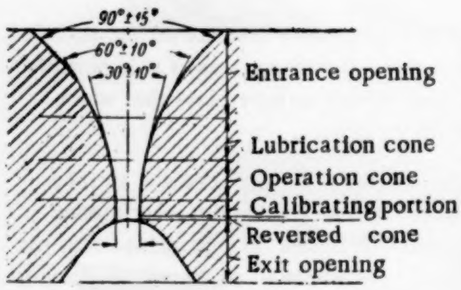


Fig. 1.

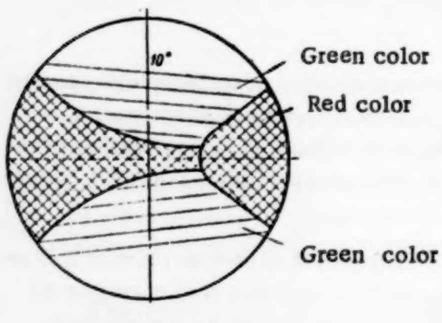


Fig. 2.

1. The instrument for measuring the diameters and contour of diamond dies consists of the following main parts: the microscope tube with a micromechanism and an eyepiece micrometer, a precision measuring plate and, an illuminator. The instrument is fixed to a stand which contains the illuminator. The upper plate contains the measuring stage and a vertical support with slides for a sliding carriage which carries the microscope tube.

The lower part of the tube has the objective fixed to it and the upper an eyepiece on a micrometer screw with a special adjustable grid and cross-hairs. For convenience of operation the microscope tube is bent to 90° by means of an auxiliary prism. The measuring stage has three independent movements: a vertical plane rocking movement, a radial and a longitudinal displacement.

The adjustable carriage of the stage moves on four ball bearings and is pressed by springs to a fixed support which is mounted on the bass plate.

Precision block gauges are placed between the ribbed and spherical stops fixed to the adjustable carriage.

For measuring the opening diameters of the die it is placed on the measuring stage with the die exit opening towards the objective. A 1 mm III or IV grade gauge block is placed between the fixed stay and the adjustable spherical and piece of the measuring stage. Next, the stage is moved by means of screws and the die is placed under the objective. By looking through the eyepiece and moving the objective the contour of the die opening is found. After focusing, the contour of the die opening is adjusted to coincide with a line on the grid of the eyepiece micrometer.

Accurate setting of the line is completed by means of the Vernier adjustment of the eyepiece micrometer drum. The setting of the eyepiece micrometer scale is noted. Then the 1 mm gauge block is replaced by a another gauge block whose length is larger than that of the first gauge by the diameter of the opening being measured (for instance by 0.03 mm). As the result of this operation the opening under test will be moved by

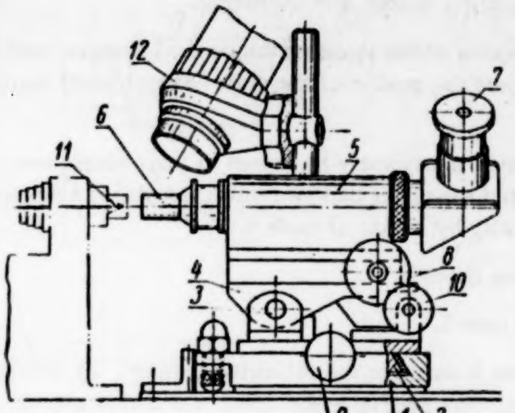


Fig. 3.

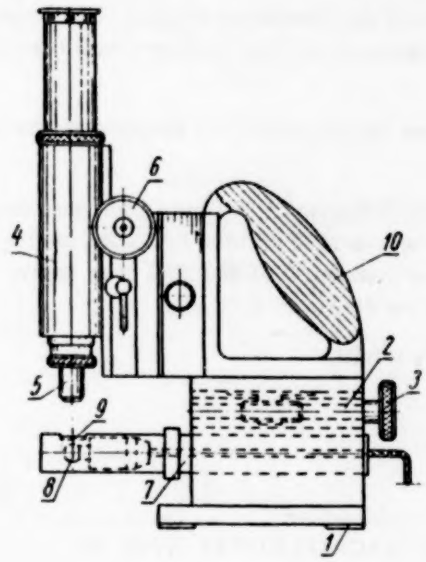


Fig. 4.

0.03 mm and the contour of the other side of the opening will now coincide with the line of the grid if the opening is 0.03 mm in diameter. If it is smaller or larger than 0.03 mm it will not coincide with the grid line. In the latter instance the line is made to coincide with the contour by means of the vernier drum, the new indication is read off the scale and the difference between it and the first setting obtained. The difference thus obtained is multiplied by the value of the scale division and the actual value of the required diameter obtained.

In order to determine whether the opening is round the die should be turned and similar measurements carried out.

The technical characteristics of the instrument are: overall magnification 495 and 120 times; the value of a division of the eyepiece micrometer scale at an overall magnification of 495 times is 0.2 μ and at a magnification of 120 times it is 0.53 μ, the maximum error of measurement with a magnification of 495 times is 0.5 μ and with a magnification of 120 times it is 0.9 μ.

2. The instrument for checking the profile of the diamond die and measuring the length of the calibrating portion of the port consists of a stand on which a measuring stage and a vertical support with the microscope tube are mounted. The lower portion of the tube carries the objective and the upper portion the ocular screw micrometer. The micrometer eyepiece has two grids: one is stationary and serves to measure angles and the other is adjustable and consists of cross-hairs.

The angular grid serves to measure the angle of the operation cone profile, the cross-hairs to measure the length of the operation cone and the length of the die calibrating portion.

The original part of the design of this instrument consists in measuring the die draw channel profile directly instead of measuring its impression. This is achieved by a combined lighting of the die draw channel. A special illuminator placed on the side of the die colors the draw channel red and the light from underneath the die colors the field of vision of the instrument green. As the result of this it is possible to see in the eyepiece a magnified sharp contour of the draw channel in red on a green background (Fig. 2).

The instrument's technical characteristics are; overall magnification of 120 and 270 times; the value of the measuring scale division 0.001 mm; error of measurement $\pm$ 1 μ at a magnification of 120 times and 0.4 μ at a magnification of 270 times.

3. The diagram of the instrument for checking the axis of the die cone against the axis of lathe spindle rotation is shown in Fig. 3.

Along slide 1 runs carriage 2 with a support whose slot carries block 4 on axle 3. The block carries a tube with an objective and an eyepiece (magnification of the objective 8 diameters and that of the eyepiece 10 diameters).

The tube can be moved in the vertical, longitudinal and transverse directions. The longitudinal movement is attained by means of a grear drive with handle 8, the transverse movement by displacing the carriage with screw 9, and the vertical by rotating the tube about axle 3 by means of the excentric drive,with handle 10.

The die is lit by illuminator 12 which consists of a lamp and a double lens condenser.

4. The diagram of the instrument for simultaneous inspection of the shape of the conical needles used for drilling the lubrication and operation cones of the die channel and the profile of the draw channel itself during manufacture is shown in Fig. 4.

Base 1 carries slides along which the microscope tube moves transversely by means of micrometer screw 2 with screw 3. The lower part of tube 4 carriers objective 5 and the upper part two interchangeable eyepieces with special angle and linear scales. The tube is moved vertically by means of knob 6.

The illuminator consists of tube 7 with lamp 8 and a green filter 9.

The lighting is adjusted by means of sliding and rotating tube 7.

The measuring of the needles and dies in situ on the lathes is made in the following manner. By means of handle 10 the instrument is placed on a plate fixed to the lathe. The needle or die under test is thus placed between the illuminator and the objective. By observing through the ocular and moving the microscope tube longitudinally and transversely the image of the needle or the die is focused in the field of vision of the instrument. The parameters of the needle or the die are determined by means of the aforementioned special grids.

If necessary the actual angle of the needle is checked by means of the coordinate method. The larger side of the triangle is determined by moving the tube in the longitudinal direction and the smaller side is read off the ocular linear scale.

The instrument provides the possibility of setting optimum angles for sharpening the needle and thus bore die profiles of a correct shape.

The technical characteristics of the instrument are: overall magnification – 80 times, transverse and longitudinal displacement of the tube – about 10 mm, the value of a micrometer division 0.01 mm, angles measured by the first grid – 10°, 20° and 30°, value of the linear scale divisions 0.01 and 0.02 mm, angles measured by the second grid – 50°, 70° and 90°, value of the linear scale division – 0.02 mm.

Above instruments have passed their field tests with statisfactory results.

CHECKING THE READINGS OF IT AND BMI MICROSCOPES AND BP PROJECTORS BY MEANS OF END GAUGES

E. I. Finkel'shtein

The method of checking measuring-microscopes by means of precision block gauges, proposed by E. E. Rusiatinskii and L. I. Demchenko (Measurement Techniques No. 4, page 20, 1957) cannot be recommended for the following reasons.

According to the technical specification for measuring-microscopes the error of measurement when end gauges only are used may reach ± 0.002 mm for gauges up to 25 mm long.

For end gauges above 25 mm the permissible error of measurement rises up to ± 0.005 mm for gauges 125 mm long.

The error is due to the inevitable production deviations from the linearity of directrixes and from defects in the mutual position of the stage surface plates, which determine the position of the block gauge during measurement.

The error of measurement by means of end gauges due to nonlinearity of the directrixes is expressed by $\Delta_1 = H_\alpha/200{,}000$ mm, where H is the height of the article with respect to the end gauge and α is the angle of

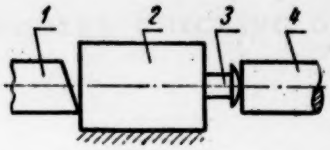


Fig. 1. 1) Rest plate; 2) end gauge; 3) spherical stop; 4) micrometer screw.

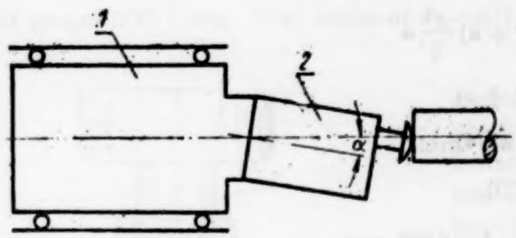


Fig. 2.

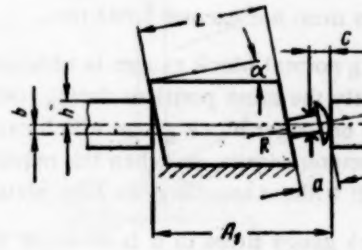


Fig. 3.

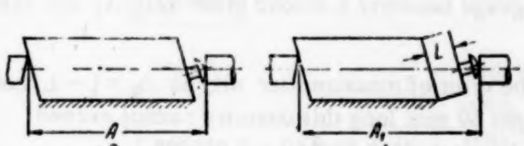


Fig. 4.

nonlinearity of the corresponding section of directrixes in the vertical plane expressed in seconds of the arc; 1/200,000 is the value of one second of the arc in radians.

With $\alpha = 10''$, H = 30 mm (the measured article is lying on the plate) $\Delta_1 = 0.0015$ mm.

With $\alpha = 10''$, H = 70 mm (the measured article is centered) $\Delta_1 = 0.0035$ mm.

The deviation from the perpendicular of the surface plate against, which the block gauge rests, with respect to the plate on which the gauge lies, also causes errors of the first order (Fig. 1).

In this instance $\Delta_2 = 0.00029\,\alpha h$ mm where 0.00029 is the value of one minute of the arc in radians; h is the distance from the axis of the spherical stop to the point of contact of the rest with the block gauge and α is the angle of deviation from the perpendicular in minutes of the arc.

If h = 1 mm, and $\alpha = 2'$, $\Delta_2 = 0.6\,\mu$. If h = 2 mm and $\alpha = 3'$, $\Delta_2 = 1.8\,\mu$.

The deviation of plate 1 movement from a line parallel to the axis of block gauge 2 (Fig. 2) causes an error of the second order which can be neglected providing the angle of deviation α does not exceed 10'.

It is obvious that above errors which can amount to a total of ± 0.002 mm in a length of 25 mm make the checking of microscopes by means of block gauges dubious without a preliminary analysis of the nature of errors involved in this method.

In addition to the above errors determined by the nature of the instrument itself there are even more important errors due to the deviations in the shape and perpendicularity of block gauges permitted by GOST* 8500-39. These deviations are completely harmless with the normal use of end gauges when the position of gauges during measuring is determined by the measuring surfaces only (telescope height gauge) or where there exists a possibility of correctly placing the gauge by rocking it (a stage of a telescope caliper).

In the case of using end measures for checking measuring-microscopes where the position of the gauge is determined by its nonmeasuring surfaces, their deviations, shape and nonperpendicularity can introduce considerable errors.

Paragraphs 13 and 14 of GOST 85000-39 determine the permissible deviation from the perpendicular of nonmeasuring surfaces of an end gauge with respect to its measuring planes as 0.2/L mm, where L is the length of the gauge.

With L - 25 mm the deviation from the perpendicular can reach 0.2/25 = 0.008 mm.

If we denote the angle of the nonperpendicularity by α, the length of the gauge by L and the distance from the axis of the micrometer screw to the edge of the rest plate by h (Fig. 3) we shall find Δ_3 from the following relationships:

$$\text{For } \alpha = 0 \quad A_1 = L + a;$$

$$\text{For } \alpha \neq 0 \quad A'_1 = (h+b)\alpha + \frac{L}{\cos\alpha} + R - \frac{R-a}{\cos\alpha}$$

*GOST = All-Union State Standard.

$$\Delta = A'_1 - A_1 = (h+b)\alpha + L\left(\frac{1}{\cos\alpha} - 1\right) +$$

$$+ R\left(1 - \frac{1}{\cos\alpha}\right) + a\left(\frac{1}{\cos\alpha} - 1\right) =$$

$$= (h+b)\alpha + \left(\frac{1}{\cos\alpha} - 1\right)(L - R + a).$$

After transformation

$$\Delta = h\alpha + (R-c)\alpha^2 + (L - R + a)\frac{\alpha^2}{2} =$$

$$= h\alpha + \frac{\alpha^2}{2}(R - 2c + L + a).$$

For $R = 20$ mm, $c = 2$ mm, $a = 4$ mm,

$$\Delta_3 = h\alpha + \frac{\alpha^2}{2}(L + 20).$$

For $h = 1$ mm $\alpha = 0.008$, $L = 25$ mm, $\Delta_3 = 0.009$ mm.

If it is considered that the value of h can in fact reach 1.5 mm measurements by means of end gauges which depend on their geometrical shape* can involve errors exceeding 0.01 mm and hence this method of measurement is unsuitable for checking measuring-microscopes whose errors must not exceed 0.003 mm.

Therefore the following method is proposed which is suitable for using normal block gauges in checking measuring microscopes. It is necessary to place all the end gauges in exactly the same positions during testing. This will be the case if in the initial condition before measuring, a 50 mm or longer block gauge which can be called the initial gauge is placed between the end rest plate and the micrometer screws, and then the required normal block gauges (for instance 5, 10, 15, 20 and 25 mm long) fitted to it without touching the base plate.

The position of the initial gauge before testing and with another block gauge fitted to it is shown in Figs. 4a and 4b.

In this instance the error due to the skewing of the block gauge becomes a second order quantity and can be neglected.

In fact if we denote the length of the fitted gauge by L, the error of measurement will be $\Delta_4 = L - L/\cos\alpha$, where α is the angle of skew of the gauge. Since for block gauges 50 mm long this quantity cannot exceed $\alpha = 0.2/50 = 0.004$, the error of measurement will be $\Delta_4 = L - L/\cos\alpha = L\ 0.004^2/2 = 0.000008\ L$.

With L = 25 mm, $\Delta_4 = 0.0002$ mm, which can be considered satisfactory.

In practice this method proved to be satisfactory. It should, however, be remembered that this method is only suitable for checking errors of reading of the instruments in question within the limits of movement of the stage by micrometer screws only. For checking readings over the whole of the stage movement, standard linear 2nd grade gauges are required.

*When delivered from the factory the measuring-microscopes and projectors are supplied with end gauges whose measuring faces deviate from the perpendicular with respect to the nonmeasuring ones by not more than 2-3' of the arc.

EFFICIENT CHECKING OF REFERENCE GAUGES FOR THREAD MICROMETERS

N. E. Ermakov

Checking of reference gauges for thread micrometers on measuring machines by means of special ball adaptors is labor-consuming and nonproductive.

The author has introduced a new and efficient method of checking thread reference gauges on micrometer height gauges IZV-1 (Fig. 1) by means of a special auxiliary face plate 1 and adaptor 2.

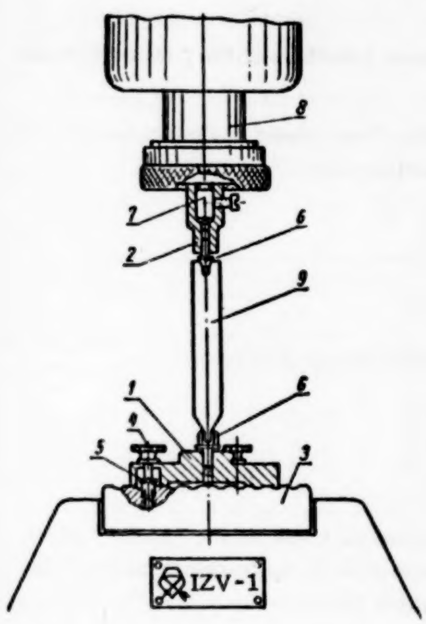


Fig. 1.

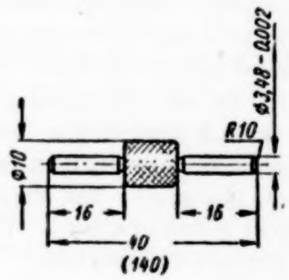


Fig. 2.

The design of the face plate and adaptor is simple and easy to produce. The plate is round and has a ground bottom surface which lies on the ribbed surface of bed plate 3. The face plate is fixed to the bed by means of three special screws 4 which fit into three threaded holes in the bed. In order to prevent the screws from falling out when the face plate is taken off they are supplied with holding washers 5, which are loosely fixed over the screw collars 4.

For fixing thread inserts 6 both the face plate and the adaptor have tight fitting holes of 3.48 + 0.005 mm in diameter. The holes go through the plate thus reducing random measuring errors due to additional packing and contact surfaces, since the inserts rest with their ground-butt surfaces straight on the surface of face plate 3 and the butt of the measuring stem 7.

Moreover this construction of the face plate and the adaptor decreases only very little the measuring limits of the instrument and provides a more accurate setting of the thread inserts with minimum play, avoiding air cushions which would be produced by a blind hole.

In adjusting the face plate for coaxiality of the setting holes with respect to each other, special cylindrical standards (Fig. 2) are used, 40 mm long for checking gauges up to 100 mm, and 140 mm long for gauges between 100 and 200 mm.

When the face plate is set by means of the cylindrical standards the instrument scale should be set to zero. This will facilitate the final setting of the instrument to zero and will free the operator from zero setting corrections.

The cylindrical standards can also be used as normal gauges when making the tight fitting holes for the inserts.

When checking the working dimensions of the reference gauges it is recommended to use two pairs of inserts of the thread micrometer: one pair of inserts No. 3 used for measuring threads with a pitch of 1-1.5 mm and another pair of inserts No. 6 with a pitch of 5-6 mm. The inserts should be specially selected beforehand for their end diameter, the angle of the profile and the displacement of the apex of the angles with respect to the end portion. The inserts should fit easily but without any noticeable play into the holes of the face plate and adaptor.

The profile angle as well as the halves of the profile angle should have no noticeable deviations when checked on a universal or measuring-microscope.

The displacement of the profile angle apexes can be checked on the spot by rotating one insert at a time in the setting hole of the face plate and adaptor. This should not produce any changes in the reading of the instrument.

The butt ends of the selected adaptors should be ground to a sphere of 10-20 mm radius in order to ensure a reliable contact with the surface of the face plate and the butt of the measuring stem.

The measuring process consists of the following: the thread inserts are placed in the setting holes of the face plate and the adaptor, the measuring spindle 8 (Fig. 1) of the instrument is lowered until the measuring surfaces of the thread inserts 6 are firmly in contact, when the instrument scale is set to zero; next the measuring spindle 8 is lifted up and the gauge 9 under test placed between the inserts and after a pause for temperature equalization between the instrument and the gauge the scale of the instrument is read.

The real working dimension is considered to be the arithmetic mean of the two measurements with the two pairs of inserts.

When checking reference gauges over 100 mm the instrument is set for the lower limit (zero position) by the standard gauge of 100 mm.

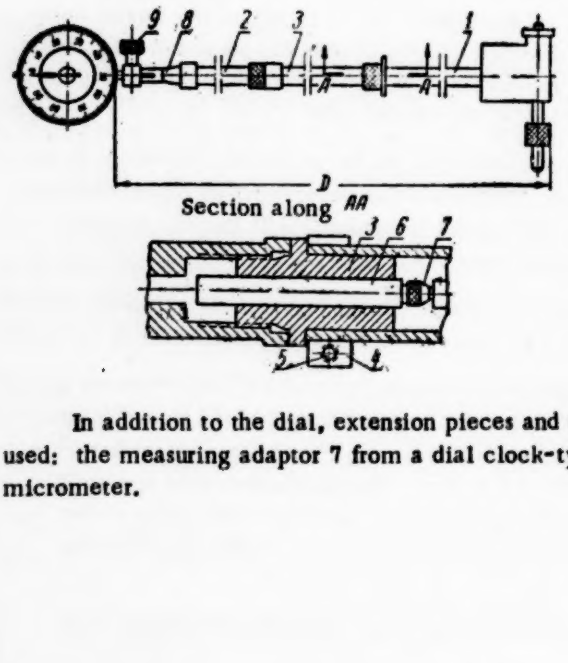
When measuring gauges it is recommended to place the prismatic insert into the auxiliary face plate and the conical one into the adaptor.

Above checking method of reference gauges for thread micrometers has been tested at the Leningrad Inspection and Checking Laboratory of the VNIIM and found completely satisfactory.

DIAL-INDICATING INSIDE-MICROMETER FOR DEEP HOLES

A. M. Startsev

The instrument consists of a conventional dial-indicating inside-micrometer made by the "Kalibr" plant connected to extensions of an inside-micrometer of the Cheliabinsk Instrument plant.



A standard inside-micrometer 1 (see figure) with the required measuring limits is disconnected from the dial-indicator with its casing and a coupling insert 3 with its connecting rod 6 is fixed to it instead, by means of collar 4 with screw 5; the rod carries a spherical measuring adaptor 7 which rests against the micrometer rod. The other end of the coupling insert is connected to an extension piece 2 of the required dimensions, at its further end the extension is screwed into grip 8. The dial-indicator is fixed in the grip by means of screw 9. Thus the inside-micrometer is prepared for operation.

In addition to the dial, extension pieces and the inside-micrometer the following standard details can be used: the measuring adaptor 7 from a dial clock-type gauge and grip 8 from a 35 mm dial-indicating inside-micrometer.

MICROMETER REPAIRS

A. V. Ervais

Micrometers should be repaired if they are worn, scratched or indented on the measuring faces of the anvil or spindle; if the measuring faces deviate from the specified degree of linearity and parallelism; if the first calibration of the graduated sleeve is overlapped; if the vernier thimble fouls the sleeve scale; if the micrometer screw turns in the set position; if the effort-adjusting device is faulty (defects in the ratchet or friction drives); if the error of readings exceeds the permissible value.

Micrometers only require to be adjusted if they have an axial play of the micrometer screw and if the vernier thimble is not set to zero.

Correction of the Micrometer Measuring Surfaces. Traces of wear, scratches nonparallel setting and irregularities of measuring faces of micrometers with limits of 0-25 and 75-300 mm are removed by means of lapping and polishing with cast iron and glass laps and cast iron plates.

TABLE 1

Limits of micrometer measurements, mm	Lap number			
	I	II	III	IV
	Height of laps, mm			
0–25	20	20.12	20.25	20.37
25–50	40	40.12	40.25	40.37
50–75	60	60.12	60.25	60.37
75–100	80	80.12	80.25	80.37

Cast iron laps are made of grey perlite fine-grained iron with a hardness of 180-200 on the Brinell scale and the glass ones from glass S-14.

Laps are used in sets of 3-4 differing from each other by 1/4 to 1/3 of a micrometer screw pitch. The dimensions of the laps comprising one set of four are given in Table 1.

The height of the laps for micrometers with measuring limits of 100 to 300 mm is chosen according to intervals given in Table 1. The cross-section of the laps can be either round with a diameter of 30 mm or square with a side of 30 mm. The deviation of the lap faces from a flat surface must not exceed 0.001 mm and the lack of parallelism between their two faces must not exceed 0.002 mm. If the laps exceed these limits they should be lapped on a precision cast iron plate by means of micro-abrasive powders (M10 at first and then M7).

The requirement of accuracy and methods of repairing them are the same for cast iron and glass laps.

The flat surface requirement of the laps is checked by means of a straight-edge rule and the parallelism of their two surfaces by means of a telescope height gauge.

For adjusting the laps and polishing the measuring surfaces of the spindle and anvil of micrometers, 200× 200 or 100 × 200 mm plates are used.

Before repairing the faces of the spindle and anvil, they are checked and washed, the micrometer screw is oiled and its movement is adjusted so that it should move easily and smoothly and without any axial play.

If any traces of wear, minor scratches or irregularities are observed on the spindle and anvil faces, they are eliminated by lapping with cast iron laps: with a preliminary abrasive paste (type GOI) 20 μ and finally with glass laps and 4 μ paste. The lapping paste, slightly wetted in kerosene, is smeared onto a comer of the plate or a round plate of 100-200 mm in diameter, and evenly spread by means of a round glass plate. The paste is spread by cotton wool over the measuring surface of the lap. In order to obtain an even layer of paste the lap is lightly wiped over a cloth folded in double and placed on the bench. The paste covered lap is then placed between the measuring faces of the micrometer (Fig. 1) and tightened with the ratchet. The lapping is done by means of rapid to and fro and circular movements of the lap until all the defects have been eliminated.

If the measuring surfaces are greatly worn and considerably out of parallel they are first lapped with abrasive paste of 40 μ, then 10 μ and finally with a paste not coarser than 3 μ until the required parallelism, linearity and polish is obtained.

The repairs are carried out in the following manner. The micrometer screw is taken out and secured in a

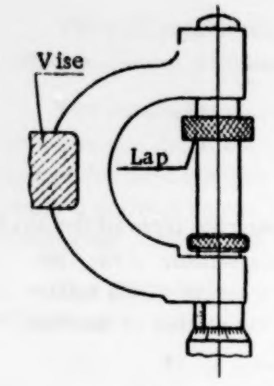


Fig. 1.

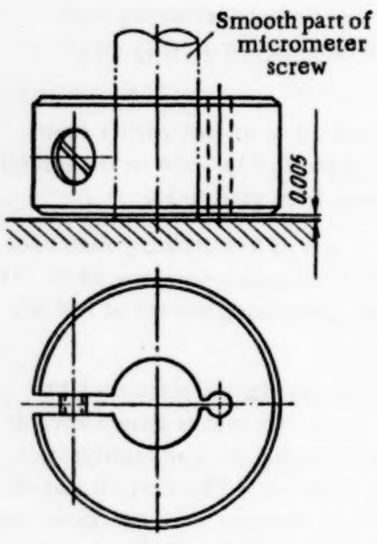


Fig. 2.

special device (Fig. 2) so that the measuring surface of the screw protrudes from the device by some 15-20 μ when lapping and by 3-4 μ when polishing. The micrometer screw is lapped on a cast iron plate with a micro-abrasive powder M20 and then M14. After three to four to-and-fro movements the device with the micrometer screw is turned through about 90° and lapped again. Having eliminated the defects of the surface the screw is replaced in the micrometer and a lap with the abrasive only on the side away from the screw and vaseline on the screw side (for lubrication) is placed between the screw and the anvil and the latter is lapped against the screw surface with the same abrasives as the screw until all the defects are removed. Following this operation both surfaces are lapped by the same method with a glass lap covered by a lapping paste.

For lapping with cast iron laps and polishing with glass laps the "Kalibr" plant uses the lapping paste given in Table 2.

The polishing of the anvils is carried out with the same plaste but with a smaller content of stearin (35 g).

In micrometers with measuring limits of 300 to 2,000 mm the parallelism of the measuring surfaces is attained in the manufacture of the micrometer frame and in the assembly of the micrometer by adjusting the frame butt which affects the direction of the micrometer unit. The only remaining problem therefore is the provision of measuring surfaces perpendicular to the axis of the micrometer. The adjustment of these surfaces is made for the micrometer screw by means of the lapping attachment (Fig. 2) and for the anvil by means of a prism. For the lapping of the anvil and the micrometer screws it is possible to use the prism square to GOST 5641-41, size type 1-2 with a cover plate and two screws.

The prism is specially lapped to obtain lines of sight deviating from a perpendicular to the base by 10-15 sec (0.002 mm in 35 mm length). If several micrometers are adjusted simultaneously a prism with several lines of sight (multiplace) can be made.

The screw and the anvil are lapped on cast iron plates with powder M20 followed by M14 and polished by powders M7 and M5.

If in large micrometers the lack of parallelism is due to the frame it is straightened by bending in the horizontal plane and by a blow of a wooden or lead mallet in the vertical plane. When a blow is stuck at the inner side of the frame (in the center of it), the measuring planes are displaced outwards, and when the blow is struck on the outer side (also in the center) the measuring planes are displaced inwards.

In closing type micrometers the anvil and the micrometer screw are fixed to the frame by means of holders which can be turned in two directions with respect to the micrometer frame.

The measuring surfaces of hard armor alloys are lapped in the following manner. The micrometer screw face is first lapped in the device shown in Fig. 2 on a cast iron plate with a diamond powder of an ~ 28 μ grain. Then the screw is replaced in the micrometer, which is held in a vise with the screw pointing downwards and the anvil is lapped with a lap covered on the anvil side only by the same powder. Following this operation the screw is again screwed out of the micrometer and lapped in a similar device on a scraped plate. A diamond 1.5 μ grain powder is used as an abrasive. Next the screw is replaced in the micrometer and the anvil face is lapped with cast iron laps and the diamond 1.5 μ grain powder. The diamond powder is kept in a porcelain cup and wetted by a few drops of watch oil. The lapping mixture is spread by a small, pointed wooden or brass rod onto the lapped surface of the spindle or the anvil.

The diamond powder used for abrading should have a grain not smaller than 20 and not larger than 35μ. If the faces are not worn excessively lapping with a fine diamond powder is sufficient. On an average 1.25 to 1.6 mg of diamond powder should be sufficient for one micrometer.

TABLE 2

Names of components	Weight or volume	Percentage of the total weight
Chromium oxide with 4-5 μ grains	28.5 g	57
Paraffin	107.5 g	21.5
Stearin	55 g	11
Wax (or ceresin)	17.5 g	3.5
Kerosene	35 cm^3	7

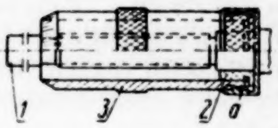


Fig. 3.

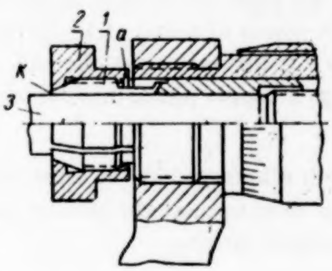


Fig. 4.

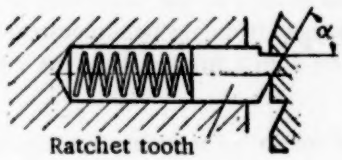


Fig. 5.

If no ready-made diamond powder is available it can be made in the following manner: 1.5-2 carats (300-400 mg) of diamond crumbs are ground in a steel mortar and placed in glass jars of 60-65 mm in diameter and 300 cm^3 in volume filled with olive oil up to a level of 90-100 mm.

Conditions of fractional sedimentation for powder No. 0 (grains of $60-10\ \mu$) – 14 hours; for No. 2 (grains $7-5\ \mu$) – 55 hours; for No. 3 (grains $5-3\ \mu$) – 77 hours and for No. 4 (grains $3-1\ \mu$) – 155 hours. On completion of sedimentation the oil is poured out of the jar and the remaining sediment of diamond dust with oil (a few drops) is used for polishing hard alloys.

The cleanliness of the steel faces of the spindle and the anvil must not be less than the 12th grade and of the hard armor alloys not less than the 11th grade according to GOST 2789-51. The deviation from linearity must not exceed three interference fringes and from parallelism by the values given in the GOST for micrometers.

Overlapping of the calibrated sleeve graduation by the beveled edge of the thimble occurs in micrometers with hard anvils and can be eliminated in several ways. In the "Kalibr" plant micrometers, this defect is easily rectified by moving the micrometer screw 1 (Fig. 3) in bush 2, which is pressed round the micrometer screw. For this purpose the screw is held by the bush in a vise with brass clams and the screw is lightly hit through a brass rod. If the thimble edge on the contrary does not reach the graduation when the spindle and the anvil are pressed together the screw is knocked in the opposite direction. The overlapping of the graduation can also be eliminated by grinding butt end a of thimble 3. In the "Krasnyi Instrumental "shchik" plant micrometers, the overlapping of the graduation can be eliminated by changing anvils. The material of which the anvil is made is steel U10 and U12; of a hardness of 58-64 by the Rockwell scale after thermal treatment.

In the Zeiss micrometers the thimble can be displaced by means of metal or plastic washer with parallel sides (within 0.01 mm) placed between the collar of the micrometer screw and the thimble butt end.

In all the micrometer types overlapping can be sometimes eliminated by grinding the bevel edge of the thimble but not more than 0.3 mm, since the thickening of the thimble edge will lead to errors in reading due to the parallax effect.

When the measuring faces touch, the graduation of the sleeve scale should be completely visible (an overlap not exceeding 0.07 mm is allowed) but the distance from the end of the conical part of the thimble to the graduation should not exceed 0.15 mm. The wobble at the thimble end must not exceed 0.15 mm.

The fouling of the scale sleeve by the thimble can be due to inaccurate positioning of the scale sleeve in assembly or to damage to the lower face of the micrometer screw bush (Fig. 3). In the first case the defect is rectified by accurate fixing of the thimble; in the second case if it is a "Kalibr" micrometer the skewing is rectified by lapping with an "Arkansas" block the bearing face of the micrometer screw; in the "Krasnyi

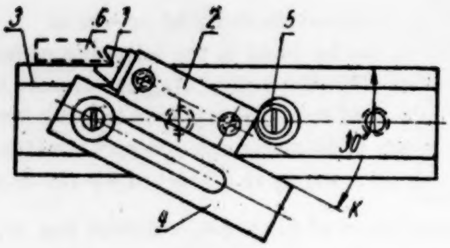


Fig. 6.

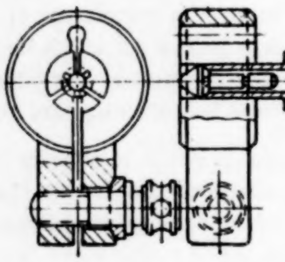


Fig. 7.

Instrumental 'shchik" micrometer it is eliminated by a special broach with a guiding spindle which is centered through the connecting bush onto the hole of the thimble; in the "Zeiss" micrometer it is eliminated by reaming the bearing shoulder of the thimble with a reamer with two guides.

Defects in the locking device. The micrometer locking device in the majority of micrometers is made in the form of a spring finger type sleeve lock (Fig. 4). The insecure fastening of the micrometer screw is due to the wear (or straining) of the spring fingers 1 or the wear of the thread of sleeve 2. The lock is repaired by grinding the butt end a of sleeve 2. This allows the sleeve to slide further over fingers 1. If the lock is operated the screw should not move when a turning effort is exerted against it. In "Kalibr" micrometers, which have a locking device in the form of a lever with a notch, the notch is adjusted when the device becomes faulty.

The elimination of radial play in the micrometer screw is done by expanding the edges of the hole which takes the micrometer spindle by means of a ball of 10-12 mm in diameter. For this purpose screw 3 is first taken out, the ball is placed on the end of the hole and gently struck by a hammer several times through a copper plate, thus decreasing the hole diameter.

If the micrometer has a finger type sleeve lock, (Fig. 4) the play is eliminated by the same method, but the screw is first taken out and then the locking sleeve is turned on tight so as to close the slits between the fingers. The life of a micrometer repaired for this defect amounts to several months.

Deviation of the setting effort outside the permissible limits. The value of the setting effort (it should be between 500 and 900 g·cm) depends on the characteristic and tension of the spiral spring and pitch angle α of the ratchet teeth (Fig. 5). In practice the measuring effort is controlled mainly by the tensioning of the spring or its substitution by a new one. If the pitch angle of the ratchet is changed it should be remembered that the smaller the angle the smaller will be the exerted effort. In micrometers with a friction drive the effort is adjusted by tensioning the spring.

Errors of micrometer reading arise due to unequal (local) wear of the thread resulting from measurement of details of the same size. Local wear becomes apparent by a jerky movement of the micrometer over the scale. If the error in the pitch of the micrometer screw and nut combination does not exceed 0.01-0.015 mm the defect can be eliminated by their mutual lapping. First the error of the screw and nut combination is accurately determined, then the screw is removed and covered with $20\,\mu$ lapping paste and screwed back into the sleeve and tightened by the control cone nut over the tight portions of the movement. The slack portions are not lapped. The lapping is done by screwing and unscrewing the micrometer. During lapping the control nut is slightly tightened 2-3 times only over the portions of the thread which are tight, until smooth motion is obtained, the whole length is lapped until the micrometer moves smoothly over the entire length of the scale. During the lapping of the screw and nut and on its completion they are carefully washed several times in benzine, smeared in watch oil and the error in the pitch of the micrometer is then checked. For more efficient lapping the micrometer frame is placed in a vise and the thimble is rotated by means of a cord taken round it in a "figure-eight."

Micrometers with inserts are repaired in a similar manner. The repair of prismatic inserts is peculiar. They can be repaired by lapping their faces by means of the device shown in Fig. 6. Insert 1 is placed in prism 2 which is fixed to rule 3 of the lapping block 4. One side of the prism is set parallel to the working surface K of block 4. Support 5 of prism 2 is eccentric and provides displacement of the surface being lapped in line with its height. Lap 6 (shown by a dotted line) is made with an angle on one of its sides a little smaller than the angle of the prismatic insert. The lapping is made with lapping paste of 10 and 3 μ or micro-abrasive powder M14 and M17. On completing the lapping of one side the insert is turned through 180° and the other side is then lapped.

Cone inserts whose shanks are worn are either chromium plated or scrapped.

If the cone of the inserts is worn they are fixed in a precision drill chuck and ground on a cylinder – and-cone grinding machine. After grinding the insert is checked and if the deviation of the apex of the angle from the axis and the error in the angle between the axis and the sides of the cones agree with the requirements of GOST 4380-48 the insert is polished.

The butt face of the head is first ground on a plane grinding machine in a prismatic device or lapped by hand on a cast iron plate in the device shown in Fig. 7. As an abrasive, powder M7-M10 is used. The grinding of the butt face of inserts, especially of inserts for checking threads with a pitch of 0.4 to 1 mm, can be replaced by lapping on a cast iron plate in the device shown in Fig. 7 with polishing paste of 20-28 μ.

If the dimensions of the butt face of the insert are out, the insert is changed to the next nearest size.

The insert can also be lapped in the above mentioned device on a flat lapping block made of Belorets quartz ("Arkansas" type) of dimensions $20 \times 10 \times 100$ mm or on a lapping block with a grain of M14 or M28. The butt face must be perpendicular to the insert axis.

After grinding the insert cone is polished on a polishing head or a cylinder- and- cone grinding machine by means of a flat cast iron lap with a paste of 10-20 μ and finally on a wooden lap with a paste of 2-3 μ.

Above methods refer to the repair of micrometers produced at home or abroad since the construction of all the micrometers is identical.

MEASUREMENTS OF MASS

ELECTRONIC ANALYTICAL BALANCES

A. A. Sokolov and V. I. Aleksandrov

The electronic analytical balance described below was designed for quick weighing of steel samples when making a rapid analysis. The mechanism of a conventional equal-arm analytical undamped balance type VA-200 made by the "Gosmetr" plant was used in the construction of the instrument. The conversion of this balance into an electronic one consisted in providing feedback to the moving system and replacing the weights by a force developed by the magnetic field of a coil.

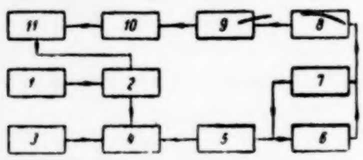
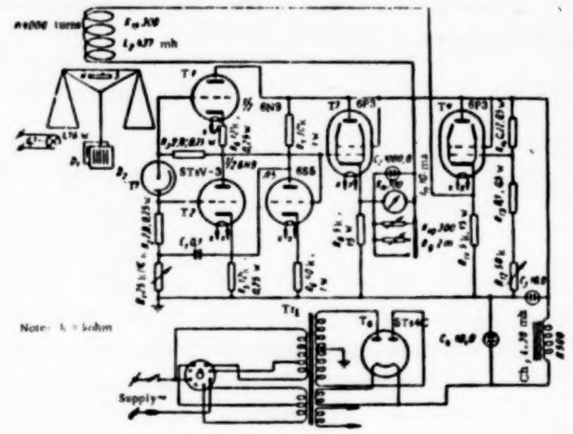


Fig. 1. 1) Weight; 2) balance; 3) source of light; 4) diaphragm; 5) photo-electric element; 6) dc amplifier; 7) differentiator; 8) power amplifier; 9) indicating instrument; 10) control coil; 11) permanent magnet.



The end of the balance pointer was firmly fixed to a blind which consisted of a thin small textolite plate with equally spaced slots parallel to the pointer axis cut in it.

A similar stationary blind was rigidly fixed to the balance stand opposite the first blind. The light of an incandescent bulb was made to pass through a condenser, a diaphragm, the two blinds and to fall on a photoelectric element which was connected to the input of a dc amplifier.

The first stage of the amplifier is a series balanced circuit. Similar resistances of the photoelement STsV-3 are connected to each grid of the two series tubes of the stage, whose gain under these conditions with respect to a voltage across one of the grid resistances is:

	T1	T2	T3	T4	T5	T6	T7
U_a	330	153	330	330	233	315	153
U_g	−2.4	−2.4	−7.2	−10.8	−3	—	—
U_k	171	156	165	165	72	282	152.0

U_{R1+R2}	U_{R3}	U_{R4}	U_{R5}	U_{R6}	U_{R7}	U_{R8}	U_{R9}	U_{R10}	U_{R11}	U_{R12}	U_{R13}	U_{R14}
0.11	0.11	2.4	2.34	161	97	165	0	0	165	24	129	177

Fig. 2.

$$K = -\mu,$$

where μ is the static amplification factor of tubes T_1 and T_2. Since μ of a triode a practically independent of the anode current the gain of the triode remains constant with time. The drift of a series stage is very small [1].

The second (amplifying) stage consists of an asymmetrical parallel balanced circuit with a large drive.

Fig. 3.

The amplification factor of a balanced amplifier is very stable and its drift is very small [2]. The load of the output stage is connected between the two cathodes of the tubes of this stage; the load consists of a milliammeter (300 ohms, 10 ma) connected in series with the coil whose field interacts with that of a permanent magnet rigidly fixed to the beam of the balance. The block schematic of the electronic analytical balance is given in Fig. 1, its full schematic and the chart of voltages in Fig. 2 and the method of connecting the permanent magnet, the coil and the blinds is shown in Fig. 3.

It is obvious that the electronic analytical balance is in fact an automatic regulator with an important feature which consists of using a constant gain servo-mechanism. This feature provides a simpler amplifier circuit and a smaller gain without increasing the static error of the regulator.

In order to ensure stable operation of the regulator, i.e., in order to damp the oscillations the amplifier input is fed with the derivative with respect to time of the output voltage. The differentiating circuit consists of the variable resistance of 25 kilohms (connected in series with the photoelement resistance of 2.8 meg in the grid circuit of the input tube) and the capacity of 0.01 μf connected to the anode of tube 6S5, whose grid is connected to the input of the first stage of the amplifier. The gain of tube 6S5 is small since it has a large automatic biasing resistor. The main purpose of the tube is to reverse the phase of the voltage in order to compensate for the phase reversal introduced by the series input stage. Such a damping system is easy to adjust. Without any load on the balance pans the deflection of the output meter pointer is adjusted to zero by means of resistor R_{12} which varies the voltage supplied from the anode potential divider to the grid of the second tube of the output stage. Then by means of a pair of tweezers a weight should be placed on the balance pan and taken off again, this process being repeated several times while the differentiator resistance R_1 is slowly adjusted at the same time until the placing of the weight on the balance no longer causes any swinging of the balance. After the differentiator has been adjusted, tapping of the table with one's hand or dropping of a weighing sample on the pan from a height of 10 cm should not affect the stability of the system. Large changes of the supply voltage should not affect the reading of the output instrument either. If the differentiator resistance is short circuited, however, the system becomes very unstable, the balance beam begins to swing by itself and continues to swing until it falls off the prismatic supports.

The bulb which shines on the photoelement is fed from the ac line. The alternating component of the photo-electric current is amplified and produces an alternating flux which relieves the friction at the balance beam fulcrum. The instability of the electronic balance readings is in practice the same as that of the balance before it was converted into an electronic one. An instability of 1 mg is allowed by the technical specification, in practice it was of the order of 0.2 mg. It was determined by weighing the same sample several times.

The output current reaches a stable state in about 0.1 sec after the weighing sample is placed on the pan of the balance.

The weighing time is equal to the time it takes the output meter pointer to reach its deflection which is about 1-2 sec.

The readings of the output moving coil milliammeter are proportional to the weight of the sample (within the limits of accuracy of the output instrument and the weights used). The linear relation between the output current or voltage of the balance and the load provide the possibility of converting this balance into a recording one and use it for registering weight variations of a sample during long periods of time [3]. This is important in the study of drying, evaporation, oxidation and other processes.

The consumption of the balance is about 30 w.

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FLOTATION INSTRUMENT FOR MEASURING THE MASS OF A LIQUID

K. I. Perchikhin and V. G. Tseitlin

We consider below the mode of action and the layout of a new flotation instrument for measuring the mass of a liquid, which is simple and of universal application.

The instrument (Fig. 1) consists of a vessel, 1, with a throat marked with a datum line, and of separate float, 2.

The principle of the instrument is as follows: when a definite mass of any liquid is poured into the vessel, the float takes up an invariable position with respect to the datum line, which is independent of the density of the liquid.

To determine the shape and dimensions of the throat of the vessel and float, we use the following starting equations, the first of which is determined by the constancy of the mass of liquid poured into the vessel, and the second by the constancy of the buoyancy force acting on the float:

$$M=(V_0+V_t-V_f)\rho=\text{const}, \tag{1}$$

$$mg=V_f\rho g=\text{const}, \tag{2}$$

where M is the mass of liquid poured into the vessel; m is the mass of the float; V_0 is the volume of the lower part of the vessel; V_t is the volume of the throat up to the liquid level; V_f is the volume of the submerged part of the float; ρ is the density of the liquid; g is the acceleration due to gravity.

The datum line corresponds to the liquid level when $\rho = \rho_0$, where ρ_0 is the density of the liquid used for calibration. When the density changes from ρ_0 to ρ, the liquid level changes with respect to the datum line by an amount z (Fig. 1).

Then from (1) we have

$$\rho_0(SH+S_th-V_{0f})=\rho[SH+S_t(h+z)-(V_{0f}+V_{zf})], \tag{3}$$

where V_{f0} is the volume of the submerged part of the float when $\rho = \rho_0$; V_{fz} is the volume of the part of the float between the datum line and the level of the liquid of density ρ; S is the cross sectional area of the lower part of the vessel; S_t is the cross sectional area of the throat; H is the height of the lower part of the vessel; h is the height of the float up to the datum line.

It follows from (2) that

$$V_{0f}\rho_0=(V_{0f}+V_{zf})\rho. \tag{4}$$

From (3) and (4), putting $\rho_0/\rho = p$, we obtain

$$V_{zf}=V_{0f}(p-1), \tag{5}$$

$$(SH+S_th-V_{0f})(p-1)=S_tz-V_{zf} \tag{6}$$

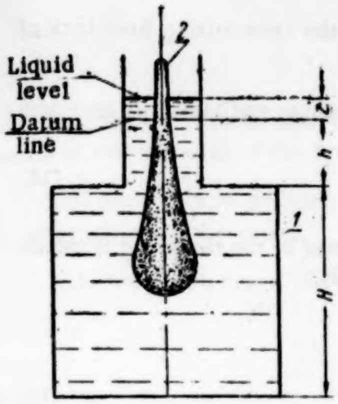

Fig. 1.

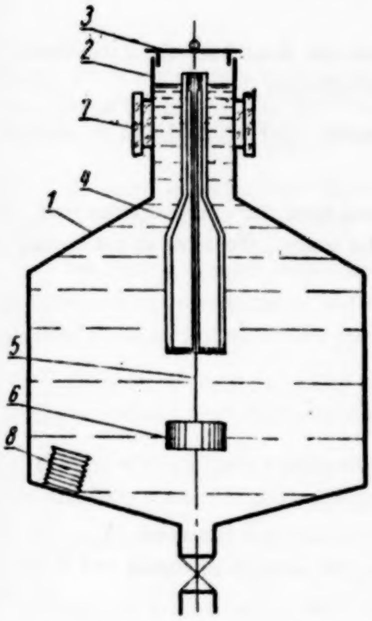

Fig. 2. 1) Body of meter; 2) throat; 3) lid; 4) float; 5) guide wire; 6) plummet; 7) viewing window; 8) temperature compensator.

Substituting the expression for V_{fz} from (5) in (6), and putting $V_0 + V_t = C$, we have

$$C(p-1) - V_{0f}(p-1) = S_t z - V_{0f}(p-1).$$

whence

$$p-1 = \frac{S_t z}{C}. \quad \textbf{(7)}$$

Assuming that the area of a cross section of the float between the datum line and the liquid level $S_f = f(z)$, we may write

$$V_{zf} = \int_0^z S_f\,dz. \quad \textbf{(8)}$$

Simultaneous solution of (5), (7) and (8) gives

$$\int_0^z S_f\,dz = V_{0f}\frac{S_t z}{C}. \quad \textbf{(9)}$$

The identity (9) can only be true if

$$S_f = S_t\frac{V_{0f}}{C}. \quad \textbf{(10)}$$

Multiplying and dividing the right hand side of (10) by ρ, we have

$$S_f = S_t\frac{m}{M+m}. \quad \textbf{(11)}$$

If account is taken of the mass m_k, of the meniscus round the float, then (11) takes the form

$$S_f = S_t\,\frac{m+m_k}{M+m+m_k}. \quad \textbf{(12)}$$

Starting with a given mass of liquid and given values of the cross sectional area of the throat of the vessel and for the mass of the float, Eq. (12) determines the cross sectional area of the float.

According to (12), the measured mass of liquid is given by

$$M = (m+m_k)\left(\frac{S_t}{S_f} - 1\right). \quad \textbf{(13)}$$

The relative error in measuring the mass amounts to

$$\delta_M = \sqrt{\delta_{inst}^2 + \delta_{read}^2},$$

where δ_{inst} is the instrument error; δ_{read} is the error in reading the instrument.

According to (13), the instrument error (we neglect the error associated with changes in the capillary properties of the liquid) is given by

$$\delta_{inst} = \sqrt{\delta_1^2 + \delta_2^2} = \sqrt{\left(\frac{\Delta m}{m+m_k}\right)^2 + \left[\frac{S_f\Delta S_t + S_t\Delta S_f}{S_f(S_t - S_f)}\right]^2} \quad \textbf{(14)}$$

where δ_1 characterizes the error in determining the mass of the float, and δ_2 is the error arising from lack of constancy in the cross sectional areas of the throat and float with height (taper).

Expressing area in terms of diameter, and change in diameter in terms of length and taper, we may write

$$\delta_2 = l\frac{D}{d} \cdot \frac{dk' + Dk''}{D^2 - d^2}, \tag{15}$$

where l is the length of the working part of the throat (or float); D is the diameter of the throat; d is the diameter of the float; k' is the taper of the throat, %; k" is the taper of the float, %.

If k' = k" = K, we have

$$\delta_2 = k\frac{D}{d} \cdot \frac{l}{D-d}\,\%. \tag{16}$$

According to (15) and (16), a given value for the error determines the permissible tapers in making the throat and float.

The error, associated with deviations of the actual dimensions of the throat and float from the calculated values, is a systematic error which can be compensated for on the instrument certificate.

The mean values of S_f and S_t can be determined from repeated measurements, and Eq. (13) can be used to recalculate and adjust the mass of the float.

An estimate of the possible error in reading the instrument may be obtained from the consideration that, if there is a difference Δz between the mark on the float and the datum line on the vessel, the error in measuring the mass of the liquid will be

$$\Delta M = \Delta z\,(S_f - S_t)\rho,$$

i.e., the corresponding relative error in reading the instrument will be

$$\delta_{read} = \frac{\Delta M}{M} = \frac{\Delta z S_f \rho}{m + m_k} - \frac{\Delta z S_t \rho}{M + m + m_k}. \tag{17}$$

If follows from analysis of (17) that, in the construction, it is very easy to ensure that the error $\delta_{read} \leq$ $\leq 0.05\%$, when the liquids do not differ in density by more than 20%. Otherwise, the lengths of throat and float become too great.

Calculation shows that, for a mass of liquid greater than 100 g and when the density range of the liquids is not more than 20%, even without any special device for taking a reading, the error of measurement can be kept down to 0.1%.

The measuring principle considered above can be used for making up master and working standards, measuring out liquids in units of mass, proportioning hoppers, discrete automatic mass meters, control detecting devices, etc.

The measuring tanks require the highest precision, together with reliability in use and simplicity. These requirements are satisfied by the method of construction shown in Fig. 2.

In order that the float may occupy a definite position in the throat of the measuring tank, the center of gravity of the float should be as far as possible below the center of buoyancy (the metacenter), which can be ensured by making the lower part of the float out of material of higher density. The float should also be provided with a vertical guide wire ending in a plummet.

It is desirable to make the float as long as possible, so that it responds to the average density of the liquid in the measuring tank.

If the temperature differs by an amount, Δt, from that at which the instrument was calibrated, it is necessary to calculate the systematic error given by the formula

$$\delta_t = \left[3\alpha' + 2(\alpha' - \alpha'')\frac{S_t}{S_t - S_f}\right]\Delta t, \tag{18}$$

where α' is the coefficient of linear expansion of the material of the vessel; α'' is the coefficient of linear expansion of the material of the float.

This error may be avoided by fitting a compensator, 8 (Fig. 2), consisting of a bellows (or aneroid can) of air, soldered inside the vessel.

The characteristics of the compensator must satisfy the following formula [1]:

$$\Delta V = F\lambda = Mn_1\Delta t, \tag{19}$$

where

$$n_1 = \frac{3\alpha' + 2(\alpha' - \alpha'')\frac{S_t}{S_t - S_f}}{\rho_{av}}. \tag{20}$$

Here, ΔV is the change in volume of the bellows corresponding to a change in temperature, Δt; F is the effective area of the bellows; λ is the change in height of the bellows for a change in temperature Δt; M is the mass of liquid to be measured; ρ_{av} is the average density of the liquid.

By selecting a bellows with these characteristics, it is possible to compensate for 90% of the temperature error, when $\rho_{max}/\rho_{min} = 20\%$.

Measuring hoppers differ from measuring tanks only in the use of an automatic device for automatically terminating the operation of adding the liquid when a given mass is attained. Such devices may consist of induction coils activated by the position of the float, contacts operating to close valves of by-pass tubes, etc.

Discrete meters consist of two or more measuring hoppers operating continuously (one emptying, the other filling); special devices count the number of switching pulses.

The authors have constructed experimental measuring tanks for 500 g of liquid. Experiment showed that the maximum error in measuring different liquids (for example, water, kerosene, benzine) did not exceed ± 0.15%.

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MECHANICAL MEASUREMENTS

PORTABLE MULTI-LEVER DEVICE WITH 100-100,000 kg RANGE

I. S. Gorpinchenko

The portable multi-lever device is intended for the measurement of force or mass and can be used for the checking and adjustment of instruments for measuring weight and force. The design was based on a scheme involving the use of levers connected in series, since this achieves a higher precision than the systems employing levers connected in parallel.

The main problem was to determine the minimum number of levers which would ensure the required accuracy at lowest weight, range.

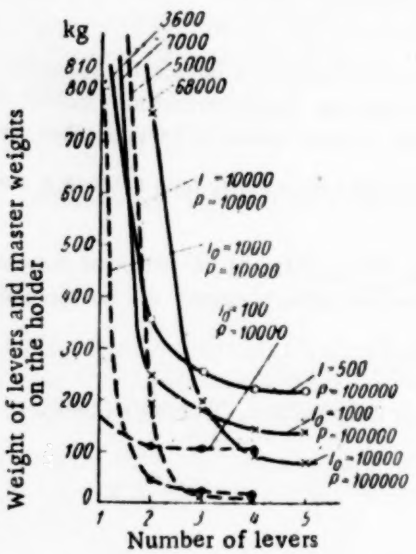


Fig. 1.

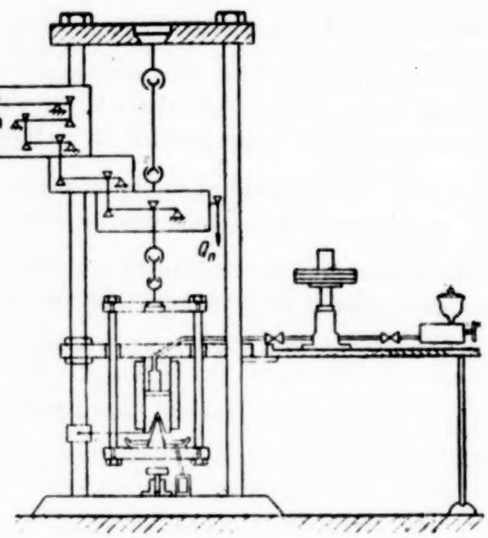


Fig. 2.

The following simplifying conditions were assumed in solving the problem

1) for different loads, levers with geometrically similar cross section were used;

2) the system was calculated for bending stresses and

3) the system consisted of levers of equal length and the same transmission ratios.

The cross sectional area of a lever is

$$F = \sqrt[3]{\left[\frac{k\left(P - \frac{P}{i_n}\right) C_0}{[\sigma]\sqrt{m}}\right]^2}. \qquad (1)$$

where P is the load on the lever in kg; i_n is the lever ratio; C_0 is the short arm of the lever; $[\sigma]$ is the working stress in kg/cm^2, and k and m are coefficients which depend on the shape of the lever cross section.

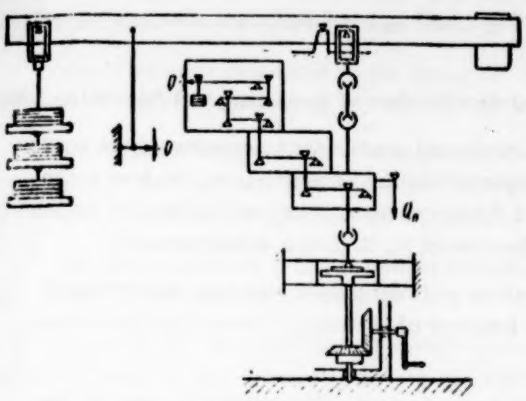


Fig. 3.

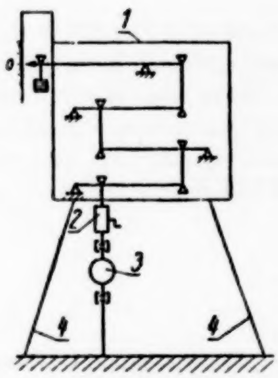


Fig. 4. 1) Portable multi-lever device; 2) jack; 3) dynamometer being calibrated; 4) supports.

The weight of the lever is given by the expression

$$G_n = a_0 P^{\frac{2}{3}} \left(\frac{i_n - 1}{i_n} \right)^{\frac{2}{3}} \qquad (2)$$

where

$$a_0 = \gamma \sqrt[3]{\frac{kC^2_0}{[\sigma]^2 m}}\, l_0 ,$$

l_0 is the lever length.

For a system incorporating n levers the weight of each lever is determined by the equation

$$G_p = \left(\frac{P}{pi} \right)^{\frac{2}{3}} \cdot (i-1)^{\frac{2}{3}} , \qquad (3)$$

where p is the number of the lever.

The total weight of the levers is determined as

$$G = \sum_1^n G_n = a_0 \left(\frac{P}{I^{\frac{1}{n}}} \right)^{\frac{2}{3}} \cdot \left(I^{\frac{1}{n}} - 1 \right) \left[1 + \left(\frac{1}{I^{\frac{1}{n}}} \right)^{\frac{2}{3}} + \left(\frac{1}{I^{\frac{2}{n}}} \right)^{\frac{2}{3}} + \ldots + \left(\frac{1}{I^{\frac{n-1}{n}}} \right)^{\frac{2}{3}} \right], \qquad (4)$$

where I is the transmission ratio of the system.

The expression (4) shows that for a single-lever system and the given values of P and C_0, the weight of the lever increases with the increasing transmission ratio, while an increase in the number of levers with other conditions remaining unchanged leads to a reduction in their weight up to a certain limit.

It can be seen from Fig. 1, which shows the relationship between the number of levers and their weight for various transmission ratios and various measurement ranges, that for loads up to 10,000 kg a three-lever linkage with a transmission ratio of I = 1000 produces the best results.

A system consisting of four levers is the best for the measurement range extending to 100,000 kg. In this case the use of a three-lever system would increase the weight of the linkage 2-3 times, while the addition of a fifth lever would reduce the weight by only 10-15%.

The overall dimensions of the portable device for measuring up to 10,000 kg are: 500 × 400 × 200 mm, and its weight is 50 kg; the overall dimensions of the device for measuring up to 100,000 kg are 1200 × 700 × × 400 mm, and its weight 180 kg.

The investigation of experimental portable devices for measuring 1000, 5000, 10,000 and 50,000 kg, with transmission ratios 500, 2500, 5000 and 25,000 respectively showed that their maximum errors never exceeded 0.01-0.03%.

The tests showed that the relative size of a scale division of the system becomes larger with the increasing number of levers, and can be determined from the equation

$$\lambda_{(n+1)} = k_0 \lambda_n i , \qquad (5)$$

where λ_n is the relative size of the division of an n-lever system, λ (n + 1) is the relative size of a division of

an n-lever system to which a lever with a lever ratio i has been added, and k_0 is a coefficient obtained experimentally (its values vary between 1 and 2).

The prototypes of the portable multi-lever devices were used in a number of measuring and inspection jobs.

Figures 2 and 3 show the arrangements for the inspection of stationary master dynamometers of the second class of hydraulic and mechanical (lever) devices. A further example of the use of multi-lever devices is the calibration of third-class master dynamometers and gaging units of dynamometers. The calibration can be performed as shown in Fig. 4. This method has been used in the calibration of N. G. Tokar dynamometers.

The comparison of curves obtained by means of portable devices with the graphs obtained for the same dynamometers on the VIIM device (All-Union Scientific Research Institute of Metrology) shows that the discrepancy does not exceed 0.02-0.03%.

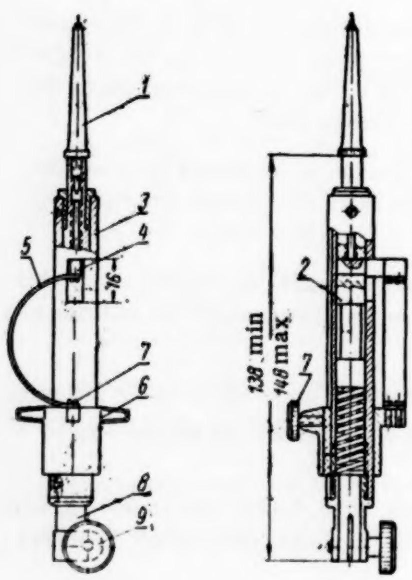
These are not all the possibilities of the application of multi-lever devices: they were also used for the adjustment and checking of wagon and truck scales, in checking scale weights of large mass, and other measurements requiring high precision.

ELECTROMECHANICAL DEFLECTOMETER

S. A. Grach

The author designed a general-purpose deflectometer (see figure) at the L'vov Technical University.

Prior to the deformation, the face of the component being tested is in close contact with the sphere of the measuring pin 1 of the deflectometer. The pin is screwed into the rod 2, and as the deformation of the specimen proceeds it moves this rod along the body 3. The bar 4 is attached by means of a screw to the rod, perpendicular to the axis of the latter. The body has a rectangular hole in which the bar together with the rod moves to and fro. One end of the small, thin rectangular beam is secured by means of two screws to the sliding sleeve 6. The sleeve with a fixed key slides along the keyway cut in the body 3. The position of the sleeve is determined by the initial radius of curvature of the beam which has been fixed during the calibration of the device. The same length of travel of the rod can produce different values of deformation of the beam. The position of the sleeve which is adopted is fixed by means of the set screw 7. For measuring small deflections, the beam 5 is made of a thin strip of rolled phosphor bronze, which has good elastic properties. For measuring big deflections the beam is made of spring steel.



The quantity being measured is transformed into electric current by strain gage wire grids cemented by means of BF-2 or BF-4 adhesive to two faces of the beam.

In order to stabilize the indications, the grids are coated with a waterproof substance (paraffin wax or bakelite lacquer).

The grids were made of 0.03 mm diameter constantin wire and had a working length of 20 mm (the ohmic resistance of a grid was about 158 Ω). When the rod moves downwards the beam becomes bent and the grids are stretched, and their cross sectional area decreases, which affects its ohmic resistance according to the relation

$$R = \rho \frac{l}{F}, \tag{1}$$

where R is the resistance of wire in Ω; ρ is the specific resistance of the wire in Ω/cm; l is the length of the wire in cm, and F is the cross sectional area in cm^2.

The wire grids cemented to the beam are connected in series in order to increase the ohmic resistance; in the case of big deformations of forces only one wire grid can be used.

A specially designed multi-channel measuring bridge with a mirror-galvanometer, or a micrommeter with a scale for visual observation or an automatic recording of the "force – deflection" diagram, is used for the power supply to the wire grid and the registering of changes in their ohmic resistance.

The deflectometer is calibrated by means of an indicator gage which is fixed with the clamping screw 9 in a specially provided split sleeve 8.

The indicator is attached to the deflectometer only during the calibration of the beam, in order to determine the value of the indicating device scale divisions of the scale or on the recorded photo-diagrams.

The deflectometer is calibrated after it has been assembled, after the replacement of the wire grids on the beam, and finally after the replacement of the beam itself.

In order to eliminate the errors introduced by fluctuations of the prevailing temperature, the circuit of one of the balance arms of the bridge contains wire grids for thermal compensation; they consist of a resistor cemented to a half-ring which is made of the same material and works in the same temperature conditions as the deflectometer beam, but is free of strain. For the accurate balancing of the bridge at the commencement of work, the compensation wire grids may be deformed (one in tension and the other in compression) by adjusting the half-ring by means of a micrometer screw.

THE USE OF RESISTANCE STRAIN GAGES FOR MEASUREMENTS IN THE FUEL INJECTION SYSTEM OF SOLID-INJECTION I.C. ENGINES

P. T. Klepach

Resistance strain gages have become widely used in the measurements of pressure and the lift of the needle in the injection systems of I.C. engines. This method of measurement is fundamentally new for fuel injection systems and the correct selection of elastic elements to which to cement the wire grids, and of the measuring apparatus is therefore of great importance. In the following we consider the setups and photographs of devices used in the investigations of the fuel injection system of the D-50 engine, and give some measurement results. During the measurements of pressure in piplines the wire grids were cemented to the bottom of the cup 1 which was installed in the body 2 (Fig. 1), since it was assumed that the frequencies of natural and free vibrations of the bottom are high. The problem of determining the frequency of free vibrations of the elastic element (cup bottom) is of real interest. The bottom of the cup can be thought of as a circular plate rigidly clamped along its circumference. During the free vibration of such a plate, i.e., when the pressure P = 0, two forces act upon its center of gravity: the elastic force of the plate ($-$ kx) and the inertia force of the plate mass ($- m\, d^2x/dt^2$).

In order to simplify the problem the resistance forces produced during the vibrations are ignored. They include the molecular forces of friction.

The equation of motion of the plate is as follows:

$$m\frac{d^2x}{dt^2}+kx=0. \tag{1}$$

As is known, the general integral of (1) is:

$$x=A\cos\omega t+B\sin\omega t, \tag{2}$$

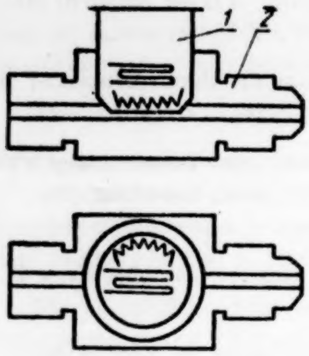


Fig. 1.

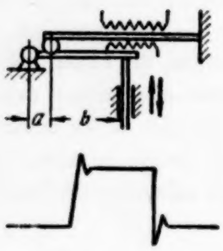


Fig. 2.

where the circumferential frequency of the natural vibrations of the bottom is:

$$\omega = \sqrt{\frac{k}{m}}. \tag{3}$$

Thus, the natural frequency depends only on the physical properties of the system: on its rigidity and mass.

Numerically the rigidity is equal to the force which must be applied to the bottom in order to alter its flexure per unit length.

For the approximate determination of the frequency of natural vibrations of the bottom we assume that

$$k = \frac{P}{f}, \tag{4}$$

where P is the force concentrated in the center of the bottom, in kg and f is the flexure in cm.

The flexure can be determined from the equation

$$f = 0.0541 \frac{Pd^2}{Et^3}. \tag{5}$$

where P is the load concentrated in the center of the bottom in kg; d is the bottom diameter in cm; t is the thickness of the bottom in cm, and E is the Young's modulus of the bottom material in kg/cm^2.

After substituting (4) and (5) into (3), and some transformations, we obtain:

$$\omega = 4.85 \frac{t}{d^2} \sqrt{\frac{Eg}{\gamma}} \text{ kc}, \tag{6}$$

where g is the acceleration due to gravity in cm/sec^2 and γ is the specific gravity in kg/cm^3.

For the steel bottom with $E = 2 \cdot 10^6$ kg/cm^2 and $\gamma = 0.0078$ kg/cm^3

$$\omega = D \frac{t}{d^2} \text{ kc}, \tag{7}$$

where $D = 24.299 \cdot 10^5$.

For d = 1.4 cm and t = 0.35 cm we obtain $\omega \approx 433$ kc.

The calculation leads to the conclusion that a high-frequency has been selected for fixing the wire grids and that the frequency of natural vibrations will not distort the process.

The bottom of the cup which carries one or two working wire grids (Fig. 1) receives the pressure prevailing in the pipeline, the bottom of the cup deforms and causes the resistance strain gage wire grid to deform and to change its resistance.

A satisfactory solution has been found to the problem of temperature compensation of the bridge when the device shown in Fig. 1 is used.

The compensation wire grid was fixed to the wall of the cup near the working grid. The cup together with the body is a very rigid system and their temperature conditions are the same as those of the bottom which carries the working grid.

For recording the lift of the injector needle, devices were constructed and tested in which a beam was used as the elastic element. The working and compensation grids were cemented to the beam. Instruments with a

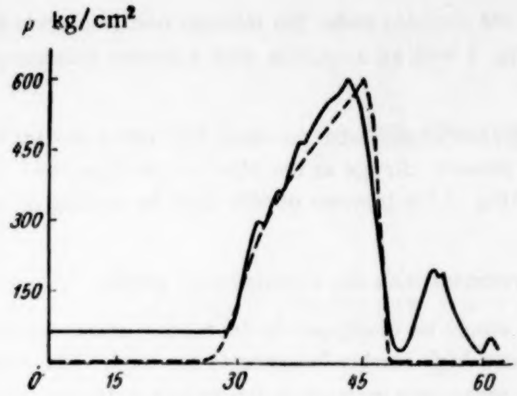


Fig. 3.

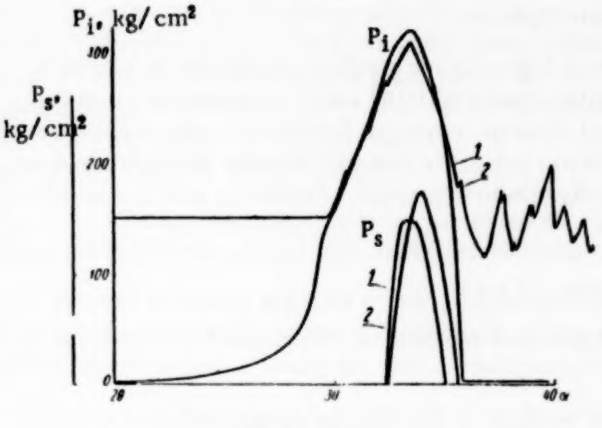


Fig. 4.

vertical, horizontal and ring-shaped beam were tested. It has, however, not been possible to obtain undistorted oscillograms with these devices. Low-frequency vibrations were produced on the oscillogram during the recording of the entire process.

Satisfactory results were obtained with the device made in accordance with the TsNIDI setup of 1955 (Fig. 2, oscillogram below the diagram). The device has an additional horizontal beam which transfers the force from the rod connected to the injector needle to the working beam. The strain gage wire grids were cemented to the working beam.

The ratio of arms a and b was selected in such a manner that the horizontal beam carries a load of about 50 kg when the load on the rod connected with the injector needle is of the order of 3 kg. Tests showed [4] that this force does not affect the motion of the plunger needle.

The parts of the apparatus are installed inside the D-50-fuel injection system as follows.

The device for measuring the pipline pressure (Fig. 1) is attached to the injector connection, and the same device is installed in the body of the injector atomizer. It was used for measuring the pressure in the channel under the seating of the injector needle (the injection pressure). Three RK-20 coaxial cables connect this device (the measuring bridge, consisting of resistance strain gage wire grids, located at the bottom of the cup) with the indicating device. The device for measuring the injector needle lift (Fig. 2) was mounted on the adjusting screw of the needle spring.

RDB-82 coaxial cable connected the measuring half-bridge, consisting of wire grids fixed on the working beam of the device, to the indicating apparatus.

It is known that the fuel injector pipeline pressure process consists of a constant (residual pressure) and variable components. The method of amplitude modulation is used for measuring such processes.

It is possible by the method of amplitude modulation to measure processes with a frequency of 10-15% of that of the alternating current supplied to the measuring bridge. In order to amplify the variations of the alternating current produced in the measuring arms of the bridge as a result of deformation of the wire grids, an ac amplifier with a carrier frequency of 5 and 50 kc was used. The properties of the amplifiers made possible the use of the type I loop of the MPO-2 oscillograph in the range of the linear relationship between the amplifier output current and deformation; the size of the oscillograms obtained was suitable for further processing.

Figure 3 shows the oscillogram of the pressure (solid line) for the injection pipeline of the D-50 engine. The oscillogram was taken with the device shown in Fig. 1 at a fuel pump shaft speed n = 370 rpm, a fuel consumption of q = 1.266 g/cycle, and with the clearance on the discharge belt of the valve δ = 0.2 mm. An amplifier was used for the recording.

The oscillogram shows a small rounding of the curve which marks the beginning of the separation of the needle from its seating ($P \approx 280$ kg/cm^2). This implies an unsatisfactory relation between the carrier frequency and the frequency of the above-mentioned harmonics of the process. The calculated (dotted) curve is also shown in the diagram. The comparison of these curves shows a satisfactory agreement between the calculated and experimental values of pressure. For comparing the results of measurements obtained with the amplifier employing carrier frequencies of 5 and 50 kc, Fig. 4 contains an oscillogram, and the calculated

pressure curves in the fuel system of D-50 (curves P_i), and in the channel under the injector needle (curves P_s). The pressure was recorded by means of the device shown in Fig. 1 with an amplifier with a carrier frequency of 50 kc at n = 370 rpm and q = 0.101 g/cycle.

A comparison of the experimental curves of Figs. 3 and 4 shows that with an amplifier with a carrier frequency of 50 kc at a low feed, all characteristic moments of pressure change in the pipeline are expressed very clearly. This applies in particular to the beginning of the lifting of the injector needle from its seating (P_i = 280 kg/cm^2; curve 2 P_i Fig. 4) and to other points.

The calculated pressure curves 1 show a satisfactory agreement with the experimental graph.

It follows from the above considerations that wire grids should be employed in the measurements carried out on the fuel injection system, especially when amplifiers with high carrier frequencies are used. The resistance wire gage has a wide range of application. It can be used for measuring pressure in the engine cylinder; the fuel injection system and collectors; for measuring the injector needle lift; displacements; angular velocities of rotating components; stresses in moving and stationary components of the engines, etc. All these measurements can be performed by means of the same experimental apparatus.

The method of measuring rapidly changing pressures in high-pressure pipelines which was developed by the author was tested in the investigation of the fuel injection systems of D-50 and V-2 engines and is in continuous use at the KhIIT, where it is used in testing the fuel injection system of the 2 D-100 engine under actual working conditions. It is also now being adopted at the Central Scientific Research Institute of the Ministry of Transport and at the chair of I.C. engines at the Kharkov Polytechnical Institute. Amplifiers with a carrier frequency of 25-50 kc are used in the investigations.

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MEASUREMENT OF TIME

GENERAL SOLUTION OF AIRY'S PROBLEM IN CHRONOMETRY

A. G. Fleer

The effect of an instantaneous pulse on the period of oscillations of a system without friction is determined by Airy's theorem [1, 2]. The proof of this fundamental chronometric theorem is usually based on a representation of oscillations as a projection of a point with a uniform circular motion onto the diameter of the circle. This representation leads to the geometrical interpretation of Airy's theorem. The theorem's propositions can also be obtained from analytical considerations [2]. B. V. Bulgakov [3] gives an analytically obtained version of the theorem for the case with friction.

The instantaneous exciting pulse, for which Airy's theorem is derived, represents only an idealized condition. In reality the pulse is distributed and possesses a certain duration.

Several particular solutions of Airy's theorem for a distributed exciting pulse are known. A. L. Rowlings [4] provides an analytical evaluation of the effect of a distributed pulse of the form $\overline{f}(t)$ = const for a period of pendilum oscillations, by using the geometrical interpretation of the theorem.

In certain instances it is possible so solve the problem by integrating differential equations of the oscillatory system's movements.

Thus Z. I. Aksel'rod [1] gives a solution of the problem for the case of a constant moment of the exciting force and for a moment which changes according to the parabolic law. Sampson [5] gives a similar solution for the case of a sinusoidal force. Other particular solutions of this problem are also known.

The effect of the external exciting force on the period of oscillations is due to the phase change of the oscillations. If the exciting pulse is not conveyed to the system at each period the system's phase changes will affect the mean value of the period. In order to provide the system with greater "freedom" i.e., to approach it to an ideal state it is naturally desirable to eliminate this phenomenon. In addition it was shown by O. V. Tupitsyn [6] that the temperature effect of a watch (in general apart from the compensated temperature coefficient of the pendulum will be at its minimum only if the external exciting pulse does not change the phase of the system's oscillations.

Let us pose the problem in the following manner: find the conditions under which the application of an external, distributed in time, exciting force of the form $\overline{f}(t)$ will not change the phase of the system. The system in this problem is not considered to be self-oscillatory but produced by forced oscillations, which is quite correct for instance for Short's free pendulum or the AChE watch.

The equation of a nonspontaneous oscillatory system without friction has the form of

$$\ddot{\varphi} + \omega^2\varphi = \overline{M}(t), \tag{1}$$

where $\overline{M}(t) = k\overline{f}(t)$.

The solution of the Eq. [7] with the initial conditions of $t = 0$ and $\varphi = A$ is:

$$\varphi = A\cos\omega t + \frac{k}{\omega}\int_{t_0}^{t} \overline{f}(\xi)\sin\omega(t-\xi)d\xi. \tag{2}$$

Let us examine the condition of the system at the instant ($t = t_1$) of the completion of the external reaction on the system

$$\overline{f}(t_1)=0. \tag{3}$$

Here $\overline{f}(t_1 - \alpha) \neq 0$ and $\tilde{\alpha}$ is any arbitrarily small interval of time.

At the instant under consideration t_1, self-oscillations of the isochronous system represented by the following equation will begin:

$$\ddot{\varphi} + \omega^2\varphi = 0, \tag{4}$$

which has the solution under the conditions given above:

$$\varphi = A_1 \cos\omega t. \tag{5}$$

Here A_1 is the new value of the amplitude of oscillations increased owing to the application of the external force.

If the phasing conditions are fulfilled, $\dot{\varphi}$ and $\ddot{\varphi}$ calculated from expressions (2) and (5) for instant t_1 will coincide. By differentiating and equating we obtain:

$$-\Delta A\omega \sin\omega t_1 = k\int_{t_0}^{t_1} \overline{f}(\xi)\cos\omega(t_1-\xi)d\xi, \tag{6}$$

$$-\Delta A\omega^2 \cos\omega t_1 = k\overline{f}(t_1) - k\omega\int_{t_0}^{t_1} \overline{f}(\xi)\sin\omega(t_1-\xi)d\xi. \tag{7}$$

Naturally (6) and (7) must have a simultaneous solution.

From (6) and (7) we have:

$$\int_{t_0}^{t_1} \overline{f}(\xi)\cos\omega\xi d\xi = \frac{1}{\omega}\overline{f}(t_1)\sin\omega t_1$$

or by denoting the variable of integration by <u>t</u> and considering (3):

$$\int_{t_0}^{t_1} \overline{f}(t)\cos\omega t dt = 0. \tag{8}$$

For system with friction integral (8) assumes the form:

$$\int_{t_0}^{t_1} \overline{f}(t)e^{ht}\cos\omega t dt = 0. \tag{9}$$

The sufficiency of condition (9) can be easily shown by carrying out a similar transformation for the case of phase inequality in the system before and after the application to it of the distributed in time external force.

Above reasoning leads to the formulation of the following theorem.

"In order that the oscillations with an amplitude incremented by the pulse should be in phase with the oscillations which existed in the system before the external pulse, which is distributed in time, was applied to it, it is necessary and sufficient that initial conditions be $t = 0$, and $\varphi = A$.

$$\int_{t_0}^{t_1} \overline{f}(t)e^{ht}\cos\omega t dt = 0.$$

In practice above condition is attained with given values of $\overline{f}(t)$ and of frequency by varying the duration of the pulse or changing instants t_0 and t_1 without changing the duration of excitation.

Assuming $\overline{f}(t)$ = const we arrive at the solution given by A. L. Rowlings [4]. If at the same time the exciting pulse is applied instantaneously, i.e., the systems coordinates at the beginning and the end of the pulse coincide ($\varphi_0 = \varphi_1 = \varphi$), the solution leads to Airy's well-known theorem. An experimental confirmation of the author's [8] calculations was obtained by O. V. Tupitsyn [6].

It should be noted that the obtained solution (9) also provides answers in the sphere of "large cps". For instance it is necessary to maintain condition (9) for the excitation condition of generators [9].

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THERMODYNAMIC MEASUREMENTS

A THERMODYNAMIC METHOD OF DETERMINING MEAN TEMPERATURE OF FLOWING GAS

K. A. Chukaev

The determination of the mean temperature in a gas stream, in particular in the firing chambers of boilers, in combustion chambers of various engines, etc., is of great practical importance. For instance, from the mean-mass temperature of the gas in the exhaust cross-section of the combustion chamber of an engine one determines the main characteristics of the combustion chamber itself and the characteristics of the engine.

One uses various methods – thermocouple, chemical, optical and thermodynamic – depending on the absolute value of the temperature and the permissible error in its determination.

Until now, thermodynamic methods have not been used extensively. The main disadvantage of these methods lies in the fact that they generally require a very accurate determination of the pressure exerted on the tube walls and of the resistances in the tube length between the two cross sections compared – the "cold" and the "hot."

In contradistinction to the existing methods based on the thermodynamic relations of the parameters of the gas under the same dynamic conditions in two cross sections, the method proposed here is based on the interrelation of the parameters of the gas under two different dynamic conditions in one and the same cross section of the tube. When the problem is approached in this way the effect of various possible stabilizing factors and of the configuration of the tube on the value of the temperature to be determined is eliminated. Thus, it is possible in a simple, reliable and speedy way to determine the temperature of the hot gas by the temperature of the gas heated to a lower temperature or even by the temperature of the cold air.

The possibility of using the cold gas flow simplifies the measurements by means of the thermodynamic methods to a great degree.

In this article the following notations are used: a) subscript of the parameters of the surrounding medium; c) subscript of the parameters of the gas in the cross section of the outlet nozzle of the tube; u) subscript of the parameters of the gas in the cross section required; x) subscript of the parameters of the cold gas in the given cross section of the tube (the absence of the index means that the parameters refer to the hot or heated gas in the given cross section of the tube); np) subscript of the critical parameters of the gas; b) subscript referring to air; t) subscript referring to fuel; F) flow cross-section area of the tube in the given cross section under investigation; F_c) flow cross-section area of the outlet nozzle of the tube; $f = F/F_c$) ratio of the cross section areas; M) M number; G) weight flow per unit time; m) mass flow per unit time; R) gas constant; L_0) theoretical quantity of air required for the combustion of one kg of fuel; g) gravity constant; k) adiabatic index; $n = k-1/k$; T) mean-mass temperature in the cross section required; p) static pressure in the cross section required; $\sigma = p_c/p$) pressure ratio; w) velocity of the gas in the cross section required; $Y = G\sqrt{T}$; α) excess air ratio; c_p) specific heat of the gas at p = const.

Derivation of the equations. Let us write the equation for the velocity of the adiabatic discharge of the gas from the outlet tube, taking into account the initial flow velocity

$$\frac{W_c^2}{gk\,RT} = M^2 + \frac{2}{k-1}\left[1 - \sigma^n\right]. \tag{1}$$

$$M^2 = M_c^2\,\sigma^n - \frac{2}{k-1}\left[1-\sigma^n\right]. \quad (2)$$

Let us transform it once again but in a slightly different manner (1). We shall replace w_c with the parameters of the characteristic equation.

We then obtain:

$$\frac{G^2\,(RT_c)^2}{(p_c\,F_c)^2\,gk\,RT} = \frac{G^2\,RT}{gk\,(p_c\,F_c)^2}\left(\frac{T_c}{T}\right)^2 = M^2 + \frac{2}{k-1}\left[1-\sigma^n\right] \text{ or } M^2\,\sigma^{2(n-1)}f^2 = M^2 + \frac{2}{k-1}\left[1-\sigma^n\right]. \quad (3)$$

$$M^2 = \frac{\frac{2}{k-1}\left[1-\sigma^n\right]}{f^2\,\sigma^{2\,(n-1)} - 1}. \quad (4)$$

If we replace M^2 by the expression

$$\frac{G^2\,RT}{gk\,(p\,F)^2},$$

then from (4) it follows:

$$T = \frac{2\,g}{R_n}\left(\frac{p\,F}{G}\right)^2 \frac{1-\sigma^n}{f^2\,\sigma^{2(n-1)}-1} \text{ For heated gas, } T_x = \frac{2g}{R_x\,n_x}\left(\frac{p_x\,F}{G_x}\right)^2 \frac{1-\sigma_x^{n_x}}{f^2\,\sigma_x^{2\,(n_x-1)}-1}$$

for the cold gas.

From these two equations we can obtain

$$T = T_x\left(\frac{G_x}{G}\right)^2 \frac{R_x}{R}\left(\frac{p}{p_x}\right)^2 \frac{k}{k_x}\,\frac{k_x-1}{k-1}\,\frac{1-\sigma^n}{1-\sigma_x^{n_x}}\,\frac{f^2\,\sigma_x^{2\,(n_x-1)}-1}{f^2\,\sigma^{2\,(n-1)}-1}. \quad (5)$$

At the same time $\underline{f}$ can be determined from the results on the cold gas flow by the formula obtained from (4);

$$f^2 = \frac{M_x^2 + \frac{2}{k_x-1}\left[1-\sigma_x^{n_x}\right]}{M_x^2\,\sigma_x^{2(n_x-1)}}. \quad (6)$$

Equation (5) is a general one and is valid for any case of gas flow. For the critical gas discharge one can obtain a simpler expression.

For this purpose we find from (2) and (3)

$$M^2 = M_c^2\,\frac{\sigma^{2-n}}{f^2} \quad (7)$$

$$\text{and } M_{np}^2 = \frac{\sigma_{np}^{2-n}}{f^2} \quad (8)$$

for any value of M_c and $M_c = 1$ respectively.

By replacing M by corresponding parameters one can obtain from (8) the following simple equation for the case of the critical gas discharge from the outlet nozzle of the tube:

$$T = T_x\left(\frac{G_x}{G}\right)^2 \frac{R_x}{R}\left(\frac{p}{p_x}\right)^2 \frac{k}{k_x}\,\frac{\sigma_{np}^{\frac{k+1}{k}}}{\sigma_{x\,np}^{\frac{k_x+1}{k_x}}}. \quad (9)$$

Experiments have shown that, with respect to the GTD combustion chamber in a range of high pressures in the tube ($p \geq 2p_a$) the expressions $\sigma_{np}^{\frac{k+1}{k}}$ and $\sigma_{x\,np}^{\frac{k_x+1}{k_x}}$ give values which differ but slightly.

Correspondingly, (9) takes the form

$$T = T_x\left(\frac{G_x}{G}\right)^2 \frac{R_x}{R}\left(\frac{p}{p_x}\right)^2 \frac{k}{k_x}. \tag{10}$$

It follows from (10) that $M = M_x$.

Hence, for the region of high pressures ($p \geq 2p_a$) when a critical gas discharge from the tube takes place, one can assume M = idem.

One should bear in mind that for an accurate determination of the temperature by means of the equations derived above, the static pressure should be measured in the direct vicinity of the outlet nozzle.

If this cross section of the tube is at a considerable distance from the outlet nozzle one should recalculate the temperature. To obtain an appropriate equation we shall make use of the theorem of the flow according to which

$$mw_u + p_uF = mw + pF$$

or

$$\frac{G^2RT_u}{gp_uF} + p_u F = \frac{G^2RT}{gpF} + pF.$$

Hence, we obtain

$$T_u = T\frac{p}{p_u} + \frac{g}{R}\left(\frac{p_u F}{G}\right)^2\left(\frac{p}{p_u} - 1\right). \tag{11}$$

It follows from (11) that, depending on the ratio of the pressures, p_u and p we can have $T_u > T$, if $p_u < p$; $T_u < T$, if $p_u > p$; $T_u = T$, if $p_u = p$. In this way one can determine the unknown temperature from the static pressures and decide when one should assume that $T_u = T$, i.e., dispense with temperature correction.

A comparison of the proposed thermodynamic method, in which the results of the investigations of various combustion chambers were used,* with the thermocouple method, showed that the maximum scatter of the points on both sides of the line of equal results does not exceed 5%.

In view of the fact that the experiments were carried out at a high gas pressure ($p > 2p_a$, the thermodynamic temperature was determined from the theoretical equation (10). From the measurements obtained by means of thermocouples, the mean-mass temperature of the gas stream was determined from the heat balance, with the assumption of c_p = idem, according to the generally accepted formula

$$T_{\text{thermocouple}} = \frac{\sum_{i=1}^{i=s}\sqrt{\Delta p_i\, T_i}}{\sum_{i=1}^{i=s}\sqrt{\dfrac{\Delta p_i}{T_i}}},$$

where Δp_i and T_i are local values of the temperature and velocity head in the cross section where thermocouples are placed; s is the number of readings.

The scatter of the experimental points should not be explained by errors in the determination of the temperature by a given method. Of course, the error in the determination of the temperature depends on the method used. For instance, one should not ignore the errors in the temperature determination by means of thermocouples if only because of the fact that the junctions of the thermocouples were not screened. Also, one

* The object of these investigations was other than direct test of the proposed method. In several experiments a very good agreement (to within 1%) between $T_{(\text{thermodynamic})}$ and $T_{(\text{thermocouple})}$ was observed.

should not ignore the errors in the determination of temperature by thermodynamic methods, which are dependent on the experimental errors in the determination of the gas parameters which enter into the equations. Thus, the scatter of the points relative to the line of equal readings is within the limits of the experimental error of each method. If the measurements of the temperatures by means of the thermocouples were more accurate the discrepancy between the values of $T_{(thermodynamic)}$ and $T_{(thermocouple)}$ would be smaller.

Analysis of the equations. Equations (5), (6), (9), (10) and (11) contain not more than three independent parameters and two constants. These parameters (G, p, p_a) can be measured simply, easily and quickly. As far as the constants are concerned, one of them – the gas constant (R) – is usually determined (independently of the requirements of temperature measurement) with sufficient accuracy. The other constant (k) at first sight appears to be undeterminable since it depends on the temperature which is also an unknown and depends on the same constant i.e., the adiabatic index. However, it will be shown that by means of the method of approximation, one can determine k with adequate accuracy.

Apart from the determination of the mean temperature, the equations derived make it possible to determine the effective flow area F_c from (6) and the limiting M number from (8). From the area F_c, one can calculate the discharge coefficient of the outlet nozzle and the reactive force of the gas stream. From the limiting M number one can, according to (10), determine the limiting values of the parameters G, T and p from two cold-gas runs without the need of heating the gas and, in particular, without fire tests of the combustion chambers.

Notes on the experimental method. Unlike the arrangement where the part under investigation is provided with thermocouples, full-pressure tubes, a screening wall and static-pressure gauges, the investigated part of the tube is arranged very simply in the proposed method. In our method there are only holes in the tube wall for measuring the static pressure but there are no parts immersed in the flowing stream. To prevent clogging of the holes, one should not arrange them in the lower part of the tube if the tube is in a horizontal position. For instance, when the combustion chamber is blown through with hot air its temperature should be measured at the outlet from the chamber. When the chamber is blown through with cold air its temperature may be measured at the inlet to the chamber if the temperature of air entering the chamber is not very different from the temperature of air in the room where the experimental apparatus is located.

The gas rate must be measured by a standard venturimeter and the compressibility of the gas must be taken into account (1). By the gas rate one should understand the total flow of air and fuel. For combustion products, one can take R = 29.5 without any appreciable error. The results of the cold blowing-through can be conveniently represented in the form of a curve $Y = G\sqrt{T} = f(p)$ for a tube with a noncontrolled outlet nozzle, or by a family of such curves for a tube with an adjustable outlet. In this way, it is possible to check the accuracy of the results on cold blowing by means of the reproducibility of the curves Y = f (p) and by the extent to which the rectilinear section of the curve approaches the origin of the co-ordinates.

The adiabatic index can be determined in the following way. Taking into account the generally small variation in the adiabatic index and the small effect of the temperature on it, we shall assume k = idem as a first approximation. The theoretical equations for the determination of temperature will then take the form:

$$T' = T_x\left(\frac{G_x}{G}\right)^2 \frac{R_x}{R}\left(\frac{p}{p_x}\right)^2. \quad (14)$$

From the approximate temperature T' and the excess air coefficient, $\alpha = G_b/G_t L_0$, we can find, for instance, [2, 3], the first approximate value k = k'. Substituting k' in one of the theoretical equations we obtain a new (second) value T = T". From this temperature, T", and the value, we find a second, more accurate, value k = k". Substituting the value k" in one of the theoretical equations, we obtain a more accurate value of the temperature, and so on. As far as GTD combustion chambers are concerned one can confine oneself to the first approximation of the value of T without an appreciable error.

SUMMARY

The proposed thermodynamic method of determining the mean-mass temperature of a gas stream in a pipe is simple, fast and reliable. By means of this method, it is possible to determine the temperature of the gas heated up to any temperature. At the same time, since it is possible to determinate accurately the parameters which enter into the theoretical equations, the error in a temperature determination can be quite low.

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A TECHNIQUE OF CALCULATING PERMISSIBLE ERRORS IN INDUSTRIAL OPTICAL PYROMETERS

A. N. Gordov and E. A. Lapina

A full description and theoretical justification of a method of calculating permissible errors in an industrial optical pyrometer as yet do not exist in the technical literature. The method of calibrating and checking these instruments is rather peculiar, and is reflected in the calculation errors which determine the expected accuracy of the temperature measured by means of the instrument.

The error of measurement of any temperature measuring instrument must be determined with respect to the international temperature scale. Hence, the permissible error of an industrial pyrometer must consist of the limiting (largest) values of the errors due to the pyrometer itself and the limiting error of the instrument used for calibrating it, in this case of a standard 2nd grade temperature lamp.

The first of these two values is determined by the constructional peculiarities of the pyrometer and characterize the permissible deviations in the readings of various pyrometers of the same type, calibrated against the same reference radiator.

The knowledge of the permissible manufacturing error of a given type of pyrometer is required for checking instruments in mass production. This value should be determined in advance from test results at temperatures close to 20°C obtained from a consignment of instruments of the same type (10 to 15 of them) which were previously calibrated against the same source.

Recent work of the VNIIM shows that the optical density of the absorbing glass plates placed in an optical pyrometer depends on the temperature of the plates themselves. A rise of temperature produces a rise of the optical density in absorbing glass plates type PS-2, but a fall of the optical density in plates NS-13 which were developed for optical pyrometers. This effect is stronger in the latter plates then in the former. The different nature of temperature response of the two types of plates, PS-2 and NS-13, suggests the possibility of using complex absorbing plates consisting of both types of glass. The thickness of these plates can be selected in such a way that the combined plate optical density will become practically independent of temperature.

It should be noted that temperature variations of the instrument cause temperature changes in the red filter which shift the passband limits of the latter. This in turn leads to a change in the effective wavelength of the pyrometer.[1] It would appear at first sight that such a change in the effective wavelength of the instrument should cause a corresponding change in the pyrometric loss of the system consisting of the absorbing glass plates and the red light filter.

In effect it is known that the pyrometric loss A is expressed by the formula:

$$A = \frac{\lambda_e \ln \tau}{C_2}, \qquad (1)$$

where τ is the transmittance factor of the absorbing glass plate with a light of wavelength λ_e. It follows from this formula that changes in the effective wavelength λ_e of the pyrometer must cause a proportional change in the pyrometeric loss.

However, the glass plates type PS-2 and NS-13, used in the Soviet optical pyrometers, are chosen only on the basis that in the pyrometer wavelength range they satisfy sufficiently well the so called Foot's criterion, i.e., they keep constant the product of $\lambda_e \cdot \log_e \tau_\lambda$.

Hence, for a changed value of the effective wavelength of the system consisting of the red filter and absorbing glass, the transmittance factor τ_λ will change so that the value of A in (1) will remain constant and thus the change of temperature of the red glass will not theoretically affect the reading of the optical pyrometer.

The effect of temperature on the optical density of the absorbing glass leads to a narrowing of the temperature range in which the basic (determined under normal conditions, i.e., at 20°C) manufacturing error of the instrument must remain constant. It appears reasonable to make this temperature range not greater than ± 5°C, hence, when an optical pyrometer is checked or used at temperature outside 20° ± 5°C it becomes necessary to correct its reading for temperature on the basis of the following considerations.

When the temperature of an optical pyrometer glass type PS-2 is raised by 10°C above the calibration temperature, the pyrometer will read low by $\Delta t_1 = 8°C$ at $T_1 = 3{,}300°K$. If the same pyrometer uses a NS-13 type glass it will, under the same conditions read high by $\Delta t_1 = 14°C$. The calculation of this additional error for another temperature T_2 can be made by means of the formula:

$$\Delta t_2 = \left(\frac{T_2}{T_1}\right)^2 \Delta t_1. \qquad (2)$$

Thus for type NS-13 glass and a temperature of $T_2 = 2300°K$ we shall obtain from this formula a $\Delta t_2 = 7°C$. This value of the additional error amounts to 0.3% of the measured temperature and cannot be neglected.

Let us now consider the second component of the permissible error of an industrial optical pyrometer, the error due to the standard 2nd grade temperature lamp.

The error of reproducing the international temperature scale by means of a 2nd grade standard temperature lamp in turn consists of two independent discrete errors: the one σ_1 due to the errors in calibrating the lamp and the other σ_2 due to errors in reproducing the temperature brightness of the lamp caused by a temperature gradient along the filament strip in the calibration region, the effect of the ambient temperature and other reasons.

Both these errors have a random nature and therefore therefore their total value should be determined according to the root mean square law:

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2}\,. \qquad (3)$$

A detailed analysis has shown that the root mean square error σ has the following characteristic values: at 900°C σ = ± 2°C, at 1,400°C σ = ± 2.5°C and at 2,000°C σ = ± 4°C.

This means that if the brightness temperature of the strip filament is, for instance, 1,400°C, then with a probability of 68% it is possible to say that the actual values of this temperature lie between 1,402.5 and 1,397.5°C. In other words the temperature will lie in 68 cases within that interval and in 32 cases outside it. If any given optical pyrometer has to be checked for higher temperatures by means of the calculation method (see instruction of the Committee of Standards, Measures and Measuring Instrument No. 167-54), the value of this error, when caused by an error of a standard lamp up to 1,400°C, can be calculated from formula (2). Thus for a temperature of 3,000°C it will be

$$\sigma = \left(\frac{3000+273}{1400+273}\right)^2 \cdot 2.5 = \pm 10°C.$$

Let us note that if the checking of an industrial optical pyrometer in the region of 2,100-3,200°C is made by means of an arc radiator (this method is more convenient for mass checking) the root mean square error of reproducing the internationational temperature scale by a standard (arc) radiator is: at 2,100°C σ = ± 7°C, at 2,500°C σ = ± 9°C, at 3,000°C σ = ± 13°C and at 3,200°C σ = ± 15°C.

The error of the standard radiator, random in its nature, will cause systematic errors always of the same sign in all the industrial instruments checked against it. However, we do not know the sign of the error and of its dimensions we only know that with a certain probability it is possible to say that it is within certain limits. Hence, it is impossible to use a correction for this error in calibrating industrial pyrometers. Thus it becomes necessary to take into account a possible error in the brightness calibration of the standard radiator when specifying the value of the permissible error of industrial optical pyrometers.

The above mentioned systematic nature of the pyrometer errors caused by errors of standard radiators invalidates the law of random summation of errors used in Eq. (3). The adding of the manufacturing error to the error of reproducing the temperature scale must be made arithmetically. The first term consists of the permissible (maximum) value of the manufacturing error caused by the constructional peculiarities of the pyrometer. It would not be incorrect to take for the second term the root mean square value of the error caused by the standard instrument. It could mean that the errors of almost 1/3 of the checked instruments would not fall within the fixed tolerance. Experience has shown that it is better to take twice the root mean square value of the error. Twice the root mean square value of the error covers 96.4% of all the possible error values, i.e., covers in practice all its possible values.

SUMMARY

The specified permissible error of industrial optical pyrometers must be determined as the sum the absolute values of the limiting manufacturing error of the instrument and twice the root mean square value of the error due to inaccuracies in reproducing the International Temperature Scale by means of a standard radiator used for calibration.

CHANGES IN THE TESTING SYSTEM IN THE FIELD OF TEMPERATURE MEASUREMENTS

B. L. Aikhenbaum

In the existing testing system, thermocouples of KhA and KhK calibration grade are tested by being compared with second-class standard thermocouples. The analysis of the permissible errors according to instruction No. 163-54 shows that the thermocouples of KhA and KhK calibration can also be tested by means of working platinorhodium-platinum thermocouples with the use of standard calibration tables as, under these conditions, the error in the thermocouple readings constitutes $\pm 0.4 - 0.3\%$ and the permissible errors in the calibration of KhA and KhK thermocouples is $\pm 1\%$. In this way, the condition of a negligible error is satisfied.

If the platinorhodium-platinum thermocouple is calibrated by means of comparison with the standard second-class thermocouple, its error would be even smaller (approximately $\pm$ 0.1-0.2%) and its stability would not be lower than that of a second-class standard thermocouple.

We think it expedient to add standard third-class platinorhodium-platinum thermocouples, designated for testing base-metal thermocouples to the testing system of instruments for temperature measurements.

At the majority of industrial establishments served by the Tashkent State Testing Laboratory for Measurements there are no second-class standard thermocouples while the Tashkent Laboratory has only second-class thermocouples. For testing thermocouples these establishments use so-called "check thermocouples," i.e., working platinorhodium-platinum thermocouples provided with certificates containing individual calibration.

Operating experience has shown that the consistency of the measurement unit is maintained.

Editor's Note: The use of standard third-class thermocouples for testing base-metal thermocouples has an additional advantage, since the contact of standard second-class thermocouples with base metals, which contaminate the standard thermocouples and change their calibration at high temperature, is avoided.

TESTING THE THERMOCOUPLES AND PYROMETRIC INSTRUMENTS

V. D. Nikiforov

The problem of the automation of thermocouple testing has been discussed in recent technical journals. The problem is very acute and its elucidation is necessary, but not in the way in which it was done in the information bulletin M-57.54/4, under topic No. 3, of the VINITI Branch. Thus, in the report "Semi-Automatic Testing of Thermocouples" by R. V. Likhachev we read: "To test the thermocouples of base metals, it is usual to use a platinum-platinorhodium thermocouple and a PP potentiometer." Such "usual" method is inadmissible. The platinorhodium-platinum thermocouple develops a very small thermal emf., and the PP potentiometer may involve an error of up to 0.1 mv, so that the experimental error may constitute approximately 10°C.

We read further, "Platinum-platinorhodium thermocouples frequently break down and this involves the consumption of valuable metals and the additional expenditure required for testing them." If certain conditions are maintained, the platinorhodium-platinum thermocouples preserve their calibrated properties and can be operated at temperatures up to 900°C for a very long time.

R. V. Likhachev devotes a great deal of attention to the thermostatic control of the free terminal of the thermocouple, but does not sufficiently appreciate the significance of the error in the determination of the thermal emf of the thermocouples where the error should be at least several times smaller than the allowable error specified for the thermocouple which is being tested. The modification of the EPP-09 potentiometer for measurements for the range of 300-900°C does not ensure the above requirement.

There is doubt as to the possibility of using the control thermocouple instead of the standard one and this is confirmed by the following. Under topic No. 34 of the VINITI Branch publication No. P-57-20/5, the results of the tests carried out at the TSNIITM on chromel-alumel thermocouples, with regard to the stability of their thermal emf in dependence on various conditions under which they are used, are reported. On repeated calibrations, substantial deviations of the original calibration of the thermocouple from the subsequent calibration are observed and then the thermal emf becomes fairly stabilized. When the thermocouple is employed at 1,000°C, its thermal emf increases rapidly during the first 20-40 hours. Hence, there are reasons for revising the existing specifications for thermocouple testing.

One cannot consider the experimental conditions in the investigation of the effect of the depth of immersion of the thermocouple on its thermal emf as satisfactory, and the results as consistent. The temperature field in the tubular electric furnace does not reproduce the industrial conditions under which the thermocouples are employed, and when the depth of immersion of the thermocouples is increased the hot junction is displaced beyond the center of the furnace into the region of a lower temperature.

The variation in the thermal emf of the thermocouples reaches a value of more than 100 μv, and, therefore they are unsuitable for use as check thermocouples and even more so as a substitute for standard platinorhodium-platinum thermocouple. For this reason, R. V. Likhachev's apparatus for the semi-automatic testing of thermocouples is of no value and should not be recommended for use.

A description of V. T. Voevoda's apparatus for the semi-automatic testing of thermocouples is given in the "Izmeritel'naia Tekhnika" No.5 1957. The testing method is based on measuring and recording the difference of the thermal emf between the controlling and the tested thermocouples. The apparatus has undisputable advantages. The use, however, of control thermocouples instead of standard ones makes the introduction of the apparatus rather difficult. In order to make it possible for the apparatus to be operated with standard platinorhodium-platinum thermocouples, it is necessary to find a rational way of equalizing the thermal emf of the thermocouples.

In comparison with the usual methods of thermocouple testing, the universal apparatus for testing pyrometric instruments described in the article by Z. I. Druker "Izmeritel'naia Tekhnika") No. 5, 1957), has several advantages owing to the use of special lever sets of resistances for checking logometers* and automatic balanced

*Instrument used in measuring current ratios.

bridges. It does not, however, provide for checking the logometers and automatic bridges of all calibration systems and for all measurement ranges (actually, the author was not aiming at this).

Hence, if such an equipment is to be designed for GKL or other establishments where various pyrometric instruments are used, it is necessary to provide a special set of resistances, class 0.02, which would have not more than five decades.

At the same time, the last decade should have the smallest division of resistances of 0.01 ohms. For a smooth approach to the tested point, it is desirable to have a variable resistance of 7 + 7 ohms with a fixed middle point in the circuit. If the resistance thermometers in use have several calibrations, it is more expedient to have the scale in the resistance units. It is necessary to start the production of similar resistance sets for checking instruments used in conjunction with the resistance thermometers. The description of the testing equipment and methods should be accompanied by editors' notes and, if additional investigations are required, there should be a note to that effect.

ELECTRICAL MEASUREMENTS

APPLICATION OF THERMOELECTRIC INSTRUMENTS AT VERY LOW FREQUENCIES

P. P. Ornat-skii

In order to find out the possibility of using thermocouple instruments at very-low frequencies (below 15 cps) it is necessary to determine the optimum inertia required for the thermoelement and to establish the relation between the inertia and the thermocouple characteristics. It is necessary to select an optimum inertia because in order to improve the measuring conditions it is obviously desirable to increase the inertia of the thermoelement, but this decreases sensitivity of the instrument and increases the stabilization time of its movement.

The thermocouple thermoelectromotive force E is proportional to the difference of temperatures between the hot and cold junctions. If the temperature of the cold junction be considered constant in a stable state, E will only depend on the hot junction temperature Θ which is approximately equal to the heating temperature. It is known that at frequencies above 15 cps the inertia of conventional thermocouples is adequate.

However, at frequencies below 15 cps their inertia may prove insufficient and lead to the appearance of alternating components $\Theta_\sim$ and $E_\sim$ in the temperature of the heater and the thermoelectromotive force respectively. The alternating component $E_\sim$ will cause oscillations of the instrument pointer and will make readings impossible. The problem consists in determining the relation between the alternating component amplitudes $E_{M\sim}$ and $\Theta_{M\sim}$ and the corresponding direct components $E_=$ and $\Theta_=$ in terms of the thermocouple parameters and in finding conditions at which the ratio $E_{M\sim}/E_= = \Theta_{M\sim}/\Theta_=$ becomes insignificant, approximately of the order of $0.5\,\gamma_p$, where γ_p is the permissible error for the given grade of instrument (in %).

For the solution of this problem let us evolve and solve an equation of the heater thermal condition. Assuming that 1) the temperature of the heater does not exceed 100-150°C; 2) the heat conduction in the thermal electrodes and blocks is small (the heaters being of a small diameter taking small currents).

The thermal state equation has the form:

$$C_H \frac{d\Theta}{dt} + H_H\Theta = I_M^2 r \sin^2 \omega t,$$

where C_H is the thermal capacity of the heater; H_H is the thermal dissipation constant of the heater; $d\Theta/dt$ is the rate of change of temperature; I_M is the maximum value of the sinusoidal current which flows through the conductor during time t and r is the heater resistance, considered constant in the first approximation, which is permissible if the heater materials have a small temperature coefficient.

The solution of this equation is [1]:

$$\Theta = \frac{rI^2}{2H_H} - \frac{rI_M^2}{2H_H}\frac{1}{\sqrt{1+(2\omega\tau)^2}}\cos[2\omega t + \mathrm{arctg}(-2\omega\tau)], \quad (2)$$

where the "thermal" time constant is equal to:

$$\tau = \frac{C_H}{H_H}.$$

It follows from (2) that the heater temperature has two components: a continuous $\Theta_=$ and an alternating one $\Theta_\sim$, where the alternating component varies at twice the rate of the current flowing through the heater.

The value of the amplitude ratio of interest to us is:

$$K_T = \frac{\Theta_{M\sim}}{\Theta_{=}} = \frac{E_{M\sim}}{E_{=}} = \frac{1}{\sqrt{1+(2\omega\tau)^2}}.$$

Since we aim at a value of K_T of the order of 0.01-0.005 it is possible to neglect the unity under the sign of the radical.

Then

$$K_T = \frac{1}{2\omega\tau}.$$

Since $C_H = mC,\ H_H = \alpha F,\ \omega = 2\pi f,$

where α is the heat transfer factor of the heater; F is the surface area of the heater; m is the mass of the heater; C is the specific heat of the heater material, it follows that:

$$K_T = \frac{\alpha F}{4\pi f m C},$$

and for a heater in the shape of cylindrical thread:

$$K_T = \frac{\alpha}{\pi f d \rho C},$$

where d is the heater diameter, ρ is the density of the heater material and f is the frequency of the current.

In order to decrease K_T it is obviously necessary to increase the thread diameter, and the specific heat of the heater and prevent heat dissipation, for instance by means of a vacuum.

Sometimes the heaters are made of alloys with a considerable resistance temperature coefficient of the order of 0.004 per 1°C. Let us examine the solution of Eq. (1) under the condition that r depends on temperature.

Assuming an exponential relation between the resistance and temperature as the first approximation $r = A\Theta^{-n}$ the solution of the equation will be: [1]

$$\Theta = \left[\frac{AI_M^2}{2H_H} - \frac{AI_M^2}{2H_H\sqrt{1+\left(\frac{2\omega\tau}{n+1}\right)^2}}\cos(2\omega t - \varphi_1)\right]^{\frac{1}{n+1}}$$

where φ_1 is the phase angle between the alternating component of temperature and the current in the heater.

Denoting $AI_M^2/2H_H = B$ and taking into account that for metallic heaters $n = -1/2$ we obtain:

$$\Theta = \left|B - \frac{B}{\sqrt{1+(4\omega\tau)^2}}\cos(2\omega t - \varphi_1)\right|^2 = B^2 - \frac{2B^2}{\sqrt{1+(4\omega\tau)^2}}\cos(2\omega t - \varphi_1) + \frac{B^2}{1+(4\omega\tau)^2}\cos^2(2\omega t - \varphi_1). \quad (3)$$

In our case $\frac{1}{\sqrt{1+(4\omega\tau)^2}} \ll 1$, hence the third term can be neglected. Then $\Theta = \Theta_{=} - \Theta_{\sim}$

In this case the amplitude coefficient is equal to

$$K_T = \frac{\Theta_{H\sim}}{\Theta_{=}} = \frac{2}{\sqrt{1+(4\omega\tau)^2}}.$$

Taking into consideration that $(4\pi\tau)^2 \gg 1$ we have:

$$K_T = \frac{1}{2\omega\tau}.$$

This proves that with above relation between resistance r and temperature the quantity K_T remains independent of temperature.

We cannot, however, judge the ratio between the alternating $\alpha_\sim$ and direct $\alpha_=$ components of the deflection angle of the moving coil instrument connected to the thermocouple by $K_T = E_{M\sim}/E_=$, since $(\alpha_\sim/\alpha_=)$ depends not only on K_T but also on the inertia of the mechanical part of the instrument.

Considering the relation of the alternating component of the pointer deflection to its parameters [2], we obtain for our case:

$$\frac{\alpha_\sim}{\alpha_=} = \frac{K_T}{\sqrt{(1-4\eta^2)^2+(4\eta\beta)^2}} \sin 2\omega t,$$

where $\eta = T_0/T_b$, T_0 is the natural oscillation period of the movement of the instrument; T_b is the period of the measured current and β is the degree of damping.

Hence the amplitude coefficient will be further decreased by a factor of: .

$$K_M = \frac{1}{\sqrt{(1-4\eta^2)^2+(4\eta\beta)^2}}.$$

The total coefficient of a thermocouple instrument's pointer alternating deflection is:

$$K_c = K_T K_M = \frac{1}{2\omega\tau\sqrt{(1-4\eta^2)^2+(4\eta\beta)^2}} = \frac{0.5\gamma_p}{100}.$$

The formula thus obtained for K_c provides the value of the required dynamic characteristic of the moving coil instrument for a given thermocouple or that of the thermal time constant of the thermocouple for a given instrument.

It should, however, be noted that the value of the thermal time constant τ of the thermocouple cannot be made as large as might be required to suppress an alternating deflection component of any size. The value of τ is limited by the required transient period of the movement. The transient period of a thermocouple instrument cannot be determined by the known formulas [3] giving the transient time for normal moving coil instruments, since the time it takes the thermocouple instruments to reach a stable state is determined in the main by the thermal inertia of the couple and not by the mechanical inertia of the movement.

In this case (with a relatively small natural period of oscillations T_0 of the movement) the temperature of the heater, the thermoelectric emf and the angle of the instrument pointer deflection will vary exponentially with respect to time:

$$\Theta = \Theta_{st}\left(1 - e^{-\frac{t}{\tau}}\right); \quad E = E_{st}\left(1 - e^{-\frac{t}{\tau}}\right); \quad \alpha = \alpha_{st}\left(1 - e^{-\frac{t}{\tau}}\right).$$

Here Θ_{st}, E_{st} and α_{st} are the stable values of the heater temperature, the thermoelectromotive force and the angle of the movement deflection respectively.

It is now required to find t_{st} as the time in which the temperature reaches the value $\Theta = \Theta_{st}(1-\Delta)$ or the deflection angle reaches the value $\alpha = \alpha_{st}(1-\Delta)$, where Δ is the given accuracy of stabilization of the values of Θ and α. It can be shown that the value of t_{st} is:

$$t_{st} = \tau \ln\frac{1}{\Delta}.$$

Taking t_{st} = 10 sec and Δ = 0.02 we obtain the thermal time constant τ = 2.6 sec. Then at a frequency of f = 0.5 cps the amplitude coefficient of the alternating component, determined by the value of the thermal time constant, will be:

$$K_T = \frac{1}{4\pi f\tau} = \frac{1}{16}.$$

Thus at f = 0.5 cps thermocouple instruments reduce the alternating component of the instrument deflection to about 1/16 (in addition to K_M is the coefficient of the alternating component due only to the mechanical inertia of the movement).

In order to check the formulas obtained for K the thermocouple instrument was tested at f = 0.5 cps. A 5 amp noncontact thermal made in the laboratory with a thermoelement resistance of 78 ohms and τ = 1.1 sec. was used in conjunction with a pyrometric millivoltmeter type GNKP of the following characteristics: T_0 = 3.4 sec., β = 0.7 with an external resistance of 78 ohms across the terminals. The total amplitude coefficient of the alternating component was then found to be:

$$K = \frac{1}{2\omega\tau\sqrt{(1-4\eta^2)+(4\eta\beta)^2}} = \frac{1}{82}.$$

In actual testing at 0.5 cps the instrument gave a constant deflection of $\alpha_= = 77$ divisions and an alternating component amplitude of $\alpha_\sim = 0.8$ divisions. Thus the amplitude coefficient of the alternating component K_{ex} obtained experimentally was equal to:

$$K_{ex} = \frac{\alpha_\sim}{\alpha_=} = \frac{1}{96}.$$

As one would expect $K > K_{ex}$, for when the formula was derived, the effect of friction, which also decreases the amplitude of the deflection alternating component, was not taken into account.

Thus, it was established that thermocouple instruments provide with sufficient accuracy and a small deflection alternating component, the possibility of measuring effective values of the current and voltage at very-low frequencies and therefore can be recommended as standard instruments as well.

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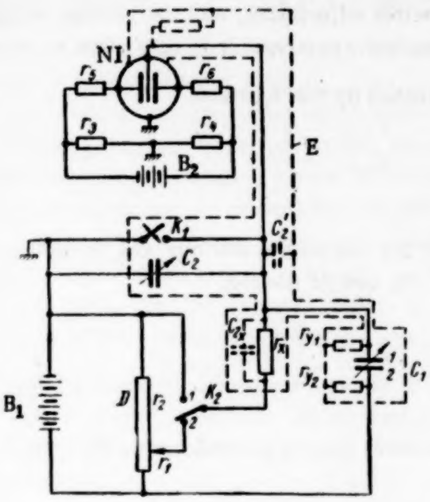
A METHOD AND EQUIPMENT FOR MEASURING RESISTANCES UP TO 10^{14} ohms

G. F. Pankratov and T. B. Rozhdestvenskaia

The widening spheres of application of very high resistances (10^7-10^{14} ohms) and the mastery of their production in the form of nonwire-wound resistors and of the technique of winding resistors with micro-wire requires the building of equipment for checking and measuring them accurately.

Until recently the All-Union D. M. Mendeleev Scientific Research Institute of Metrology (VNIIM) had equipment for measuring and checking accurately resistances only up to 10^9 ohms [1]. At present this limit has been extended. As the result of work done in 1956-1057 equipment has been produced which measured accurately resistances in the range of 10^9 to 10^{14} ohms.

The equipment is based on the principle known in the technical literature [2, 3] of discharging a capacitor at a constant voltage, the schematic (see figure) and construction of the set differs considerably from those previously described.



The basic elements of the set consist of a calibrated variable air capacitor C_1, a null indicator NI and a supply battery B_1 with a potential divider D.

Before testing starts switch key K_1, which shunts the null indicator, is closed (switch key K_2 is in position 2); capacitor C_1 is charged up to the voltage of battery B_1. The measured resistance r_x takes a current determined by its value and the voltage across part r_2 of the potential divider. When key K_1 is opened at instant $t = 0$ capacitor C_1 begins to discharge through the measured resistance r_x.

Simultaneously the capacity of the air capacitor is decreased by means of a special electric drive. The speed of rotations of the capacitor rotor is controlled in such a manner that the voltage at its terminals remains constant as shown by the null indicator NI. After the lapse of a certain time Δt (sufficient of an accurate measurement of the change in capacity ΔC of the measuring capacitor) the testing is stopped by closing key K_1 and simultaneously stopping capacitor C_1 rotor. The time is measured by means of a stop watch.

It can be easily shown that the value of resistance r_x is represented by expression:

$$r_x = \frac{1}{k} \cdot \frac{\Delta t}{\Delta C_1}, \qquad (1)$$

where $\underline{k}$ is the voltage ratio of the potential divider; Δt is the time of measurement, sec.; ΔC_1 is the change in the value of capacitor C_1 during testing; and r_x is the resistance under test, in ohms.

The basic advantages of this method are:

1) a small effect of leakage across the insulation of units and wiring on the accuracy of measurement;

2) a small effect on the errors of measurement of the stray capacities;

3) the possibility of obtaining wide measuring limits;

4) a constant voltage across the tested resistance during measurement, which is particularly important for measuring nonwire-wound resistors which vary considerably with applied voltage.

An analysis of the circuit operation leads to the following expression which takes into account the effect of leakage insulation δ_l on the accuracy of measurement (the possible leakage insulations paths and stray capacities are shown by a dotted line on the drawing):

$$\delta_l = \frac{U_0}{U_B} \cdot \frac{r_x}{r_y'} \cdot 100\,\%. \qquad (2)$$

where U_0 is the maximum voltage at the terminals of the null indicator during testing; U_B is the battery voltage fed to potentiometer D and capacitor C_1; r_x is the resistance under test; $r'_y = r_{y1} r_u / r_{y1} + r_u$ is the equivalent insulation resistance of the calibrating circuit; r_{y1} is the insulation resistance of electrode 1 of capacitor C_1; r_u is the insulation resistance of the null indicator input.

It will be seen from (2) that the insulation requirements are not very high since in the worst case when the measured resistance is equal to the insulation resistance of the circuit, the error due to leakages will be determined by the ratio of the voltage U_0 (close to zero) across the terminals of the null indicator to the voltage across the measured resistance. The difference between U_0 and zero is determined by the lack of sensitivity of the null indicator and the uneven movement of the capacitor rotor. If this voltage in the course of testing does not change its sign (the worst case) and amounts to 3-5 mv, and the voltage across the capacity under test is $U_{rx} = U_B = 10$ v* (the maximum working voltage), the leakage error will not exceed 0.03-0.05%. Under normal

*$U_{rx} = U_B$ when $k = 1$. With $k > 1$, $U_{rx} < U_B$ in the ratio of $\underline{k}$ ($\underline{k}$ being the voltage ratio of the potentiometer).

operating conditions this error is even smaller since the insulation resistance of the set normally exceeds the resistance under test, the sensitivity of the null indicator provides for a better adjustment, and the voltage across the null indicator generally changes its sign during testing and the mean voltage across it is very close to zero.

The error due to the stray capacities of the circuit can be represented by the formula:

$$\delta_c = \frac{U_0'}{U_B} \cdot \frac{C_y}{\Delta C_1}, \tag{3}$$

where $C_y = C_2 + C_2' + C_{1t} + C_{rx}$, C_{1t} is the capacity of capacitor C_1 at the end of the testing; C_{rx} is the capacity of the sample under test; U_0 is the voltage across the null indicator at the end of testing.

If it is assumed that

$$C_y \simeq \Delta C_1 \tag{4}$$

and the same circuit operating conditions obtain as in the previous instance, i.e., $U_0' = 3\text{-}5$ mv at $U_B = 10$ v, we shall obtain that $\delta_C = 0.03\text{-}0.05\%$.

It is not difficult to deduce from (3) the requirements of a null indicator. A more detailed analysis shows that the null indicator which can be used in the above circuit should have an input resistance not less than 10^{14} ohms, input capacity of a few $\mu\mu$f, a sensitivity of the order to 10^2-10^3 divisions/v, a small inertia and a good zero stability.

Let us now examine the measuring limits of this method.

If follows from (1) that the same resistance can be measured with different values of Δt, ΔC_1 and $\underline{k}$. A rational choice of these values provides the possibility of measuring resistances over a wide range. For instance in order to measure a resistance of the order of 10^9 ohms it is advisable to take a capacitor of a least 1,000 $\mu\mu$f, then the discharge time will be at least 100 sec. with a potentiometer voltage ratio of k = 100, and this will ensure the required accuracy of measurement.

From expression

$$\Delta C_1 = \frac{\Delta t}{k_{rx}} \tag{5}$$

we find that an increase in the resistance under test will decrease ΔC_1. If the time interval remains at 100 sec. as before and, the voltage ratio k = 1, a measured resistance of 10^{14} ohms will require a $\Delta C_1 = 1\ \mu\mu$f to produce above figures. Evaluation of such small changes in capacity can produce large errors; it is therefore advisable to increase ΔC_1, which can be attained by increasing the measuring time in the same proportion.

The required test voltage can be obtained by selecting an appropriate test battery and a required voltage ratio on the potentiometer. The set provides facilities for measuring at voltages ranging from 10 to 500 v. The circuit of the set and its component differ from those described in the technical literature [2, 3]. This difference ensured the possibility of extending the measuring range to 10^{14} ohms.

Let us examine the basic components and their requirement.

In the variable air capacitors produced by our industry the insulation resistance does not as a rule exceed 10^{12} ohms, which is insufficient for measuring resistances of the order of 10^{13} to 10^{14} ohms. Hence four special variable air capacitors of 1,800, 180, 20 and 4 $\mu\mu$f had to be developed (required for the entire range of measurements) with an insulation resistance exceeding 10^{14} ohms. The capacitors were made balanced to ground, which in the circuit described above provided a minimum leakage error. In fact the leakage r_{y1} across capacitor C_1 electrode 1 will be small since the potential difference between it and the screen (which is at ground potential) depends on the voltage across the null indicator, i.e., it depends only on the sensitivity of the null indicator and the accuracy of the circuit compensation during testing. The insulation resistance r_{y2} of capacitor C_1 electrode 2 shunts battery B and has practically no effect on the accuracy of measurements. In order to decrease the effect of dampness in the insulation of capacitors, provision is made for placing a drying agent inside the screen. In addition to the high insulation the calibrated capacitors must have high precision indication of

capacity changes. The capacity changes are read off a Vernier scale providing an accuracy of at least 0.01%.

In addition to the measuring capacitor the set contains an auxiliary capacitor C_2 whose capacity changes in steps of 1,500, 500 and 100 $\mu\mu$f. This capacitor ensures the validity of condition (4). It is designed to smooth out the random voltage pulses which appear on the null indicator for a variety of reasons; such as the result of an uneven capacitor rotor movement, an insufficiently smooth surface of the measuring capacitor vanes, etc. When measuring resistances above 10^{11} ohms, however, the stray capacity C_2' shunting the null indicator becomes more then sufficient for smoothing out pulses. Therefore when measuring resistances above 10^{11} ohms the auxiliary capacitor is switched out. When designing the set various components were placed in a manner to make the stray capacity C_2' as small and as stable as possible, independent of external conditions (for instance of the displacing of instruments, moving of hands, etc.). In order to avoid such effects the connecting leads are screened on the live side of the circuit, as shown on the attached schematic.

A filament electrometer type SE-2 made by the "Etalon" plant with its deflection read through an objective, was used as a null indicator. Its method of connection is shown in the schematic. Battery B_2 provides the required voltage for the electrometer plates. Resistors r_5 and r_6 protect the filament from fusing if it touches one of the plates. Resistors r_3 and r_4 serve to adjust the zero deflection of the filament by controlling the voltage on the plates. This method of connecting the electrometer provides maximum sensitivity and its input capacity does not exceed 3 to 5 $\mu\mu$f, which is smaller than the capacity of other types of indicators (quadrant electrometers, vibrating capacitor indicators). The sensitivity of the electrometer is about 200 divisions/v.

In the Bureau of Standards equipment [2] a vibrating capacitor electrometer, which has a greater sensitivity than the filament electrometer, is used. However, the input capacitance of this electrometer is higher than that of the filament type.

A considerable disadvantage for reducing leakages in the set is the impossibility of grounding the measuring circuit with a vibrating capacitor electrometer. This drawback does not exist in the VNIIM circuit. Besides the manufacturing technique of vibrating capacitor electrometers is very complicated and our industry does not as yet mass-produce such electrometers.

The schematic of our device differs from that described in [2] by the inclusion of key switch K_2 which provides the possibility of measuring the insulation resistance of capacitor C_1 without disconnecting it. It is only necessary to throw key K_2 to position 1 and without switching in the electric drive, i.e., without reducing the capacity C_1, open switch K_1. This places the resistance under test r_x and the capacitor C_1 in series. If the insulation resistance of the capacitor is large as compared with the resistance under test, the electrometer filament will not be deflected. If it is not, the electrometer filament will be noticeably deflected. It is assumed that the insulation resistance of the wiring and the electrometer is large ($\geq 10^{14}$ ohms), which is not difficult to attain.

For the rotation of the capacitor rotor an electrical drive has been designed which provides a wide and smooth variation of speed in the range of 0.06 to 2 rpm. The start control equipment of the set ensures good coincidence (with an accuracy of several hundredths of a second) of the breaking of key K_1 with the switching-in of the drive and starting of the stop watch and also of the making of key K_1 with the stopping of the drive and stop watch.

The set is equipped with a thermostatically controlled chamber which provides measurements of high resistances up to + 40°C.

Tests have shown that above equipment, UBS-1*, will measure resistances of the order of 10^9-10^{14} ohms with an accuracy of 0.2-0.5%. It should be noted that the adopted method of measurement can provide a higher accuracy, but in view of the instability of the high resistances themselves higher accuracy is not as yet required.

Side by side with set UBS-1 high resistance standards of $10 \cdot 10^8$, $10 \cdot 10^9$, $10 \cdot 10^{10}$ and $10 \cdot 10^{11}$ ohms, whose actual values do not differ from the nominal ones by more than 1-2% were also developed.

Thus the set which can measure resistances up to 10^{14} ohms with an error not exceeding 0.2-0.5% and standard resistances up to 10^{12} ohms provide the possibility of testing, in addition to standard resistances, high-resistance instruments (million megohmmeters) as well.

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*The UBS-1 set was developed under the guidance and with the participation of the author of this article by L. S. Levin and S. Ia. Poliakov and a group of VNIIM workers.

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CASCADE COMPENSATION CIRCUITS

K. B. Karandeev and M. G. Miziuk

In precision electrical measurements two types of compensation circuits are used, those with controlled resistance compensation (CRC) and controlled current compensation (CIC). Circuits of either type have their advantages and disadvantages discussed in detail in the technical literature [1-7].

Recently combined circuit including both types of compensation have been coming into use. For instance B. A. Seliber and S. G. Rabinovich [8] have used a semi-automatic compensator circuit in which the measured emf is only partly compensated by a circuit with a controlled resistance compensation and the uncompensated portion is measured by means of a photocompensator, which is a photo-electro-mechanicaldevice based on current compensation. Thus a new circuit was devised which can be called a double compensation circuit.

Other types of double compensation circuits can also be devised. Each one of these circuits has, under certain conditions, advantages over other circuits; it is therefore advisable to examine their properties.

Figure 1 shows a schematic of a double compensator whose input consists of a controlled resistance compensator circuit and the output a controlled current compensator circuit (autocompensator).

The autocompensator input (points bc) receives an uncompensated portion of the voltage:

$$\Delta u = e - u_{K_1} = \frac{e}{n}, \tag{1}$$

where n is the degree of compensation, which shows what portion Δu of the measured emf is not compensated.

The autocompensator amplifier receives voltage:

$$u_{in} = \frac{e}{n} - u_{K_2}. \tag{2}$$

The current at the output of the autocompensator is represented by the expression [7]:

$$i_2 = \frac{\frac{e}{n}}{R\left(1 + \frac{1}{\beta_1 \beta_2 K_\infty}\right)}, \tag{3}$$

where $\beta_1 = r_y / r_y + r_i + r_a + R$ is the voltage ratio factor at the output; $\beta_2 = R / r_{out} + r + R$ is the feedback factor.

The sensitivity of this system (CRC-CIC) is equal to the sensitivity of the autocompensator.

The limiting relative error of measurement of the autocompensator with a constant sensitivity C_i of the output instrument is equal to [7]:

$$\delta_{ac} = \frac{\frac{\partial\beta_1}{\beta_1} + \frac{\partial\beta_2}{\beta_2} + \frac{\partial K_\infty}{K_\infty}}{1 + \beta_1\beta_2 K_\infty} + \frac{\partial R}{R} + \frac{\partial n}{n} + \frac{\partial C_i}{C_i}. \tag{4}$$

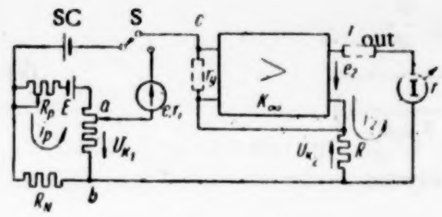

Fig. 1. A double compensation circuit with a controlled resistance compensator at the input and a controlled current compensator at the output. E) the source of the calibrating current i_p; R_p) calibrating current setting potentiometer; R_N) standard rheostat for checking the calibrating current against the standard cell SC; u_{k1}) compensating voltage of the controlled resistance compensator; $\underline{e}$ and r_i) the emf and internal resistance of the measured source; S) switch for checking the calibrating current; r_y and K_∞) input resistance and gain in open circuit of the controlled current compensator amplifier; u_{k2}) the second compensating voltage; R) the standard resistance (feedback resistance); e_2 and r_{out}) the emf and output resistance of the amplifier; i_2) the output and feedback currents; I and r) measuring instrument and its internal resistance.

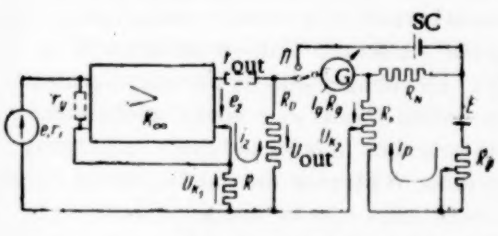

Fig. 2. A double compensation circuit with a controlled current compensator at the input and a controlled resistance compensator at the output. (designations are the same as in Fig. 1).

With a sufficiently accurate feedback resistor R, a stable $\underline{n}$ and providing condition $\beta_1\beta_2K_\infty \gg 1$ holds, the value of this error is nearly equal to the error of the output instrument:

$$\delta_{ac} \approx \frac{\partial C_i}{C_i} = \delta_i.$$

If the relative error of the compensating resistor u_{k1} is neglected, the absolute and relative errors of measurement of the emf $\underline{e}$ will be equal respectively to:

$$\Delta = \delta_i \frac{e}{n}; \quad \delta = \frac{\Delta}{e} = \frac{\delta_i}{n}. \tag{5}$$

If the degree of compensation $\underline{n}$ in the first circuit amount to 100 to 1,000, the input of the second circuit will receive a small portion of the measured voltage. Hence even with a relatively large error of the autocompensator, the error of the measured emf can be made small, which is confirmed by (5). This means that in a double compensation circuit it is sufficient to use, in order to ensure high accuracy, a two or three decade compensator resistance instead of the usual five decade one.

The input resistance of a double compensation circuit is $\underline{n}$ times greater than that of an autocompensator and is represented by the equation:

$$R_{\text{in dc}} = nr_y\,(1+\beta_1\beta_2K_\infty). \tag{6}$$

With sufficiently large values of r_y (for instance when an electronic autocompensator is used [7]), appropriate values for $\underline{n}$ and K_∞ can be assured:

$$R_{\text{in dc}} \sim 10^{10} \text{ to } 10^{12} \text{ ohms}.$$

A second type of a double compensation circuit is shown in Fig. 2. Here the autocompensator output is terminated in a standard resistor R_0, whose voltage drop is measured by a controlled resistance compensator. Selecting $R_0 > R$ it is possible to increase the output voltage of the autocompensator as compared with the measured emf by a ratio of $k = R_0/R$.

From (where in this instance $\underline{n}$ is made equal to 1) we obtain:

$$u_{\text{out}} = R_0 i_2 = k\frac{e}{1+\dfrac{1}{\beta_1\beta_2K_\infty}}. \tag{7}$$

Since the galvanometer G current is equal to:

$$I_g = \frac{a}{S_i} = \frac{u_{\text{out}} - u_{k_2}}{R_0+R_k+R_g} = \frac{ke - u_{k_2}\left(1+\dfrac{1}{\beta_1\beta_2K_\infty}\right)}{(R_0+R_k+R_g)\left(1+\dfrac{1}{\beta_1\beta_2K_\infty}\right)}, \tag{8}$$

it is obvious that the sensitivity of this system (CIC-CRC) equals to

$$S=\frac{\partial\alpha}{\partial e}=\frac{S_i k}{(R_0+R_\kappa+R_g)\left(1+\frac{1}{\beta_1\beta_2K_\infty}\right)} \tag{9}$$

and is practically $\underline{k}$ times greater than that of the CRC circuit which equals:

$$S_2=\frac{S_i}{R_0+R_\kappa+R_g},$$

where S_i is the sensitivity of galvanometer G.

Owing to the limited sensitivity of galvanometer G, when the circuit is balanced, current I_{g_0} corresponding to the deviation of the galvanometer by angle α_0 still flows in the measuring circuit.

Since

$$I_{g_0}=\frac{\alpha_0}{S_i},$$

the relative error of measurement due to the limited sensitivity is equal to:

$$\delta=\frac{ke-u_{\kappa_1}}{e}=\frac{I_{g_0}(R_0+R_\kappa+R_g)}{e}=\frac{\alpha_0(R_0+R_\kappa+R_g)}{S_i e}. \tag{10}$$

The input resistance of the double compensation circuit under consideration is equal to that of the autocompensator. The measuring limits can be changed by varying the feedback resistance of the autocompensator and thus changing its transfer factor instead of varying the operating current of the output compensator.

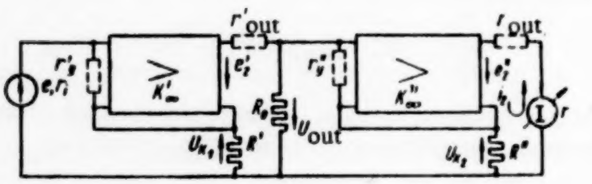

Fig. 3. A cascade autocompensation circuit (designations are the same as in Fig. 1).

The above circuit (Fig. 2) may prove to be better for measuring small voltages with a greater accuracy than would be possible with a single autocompensating circuit, especially if recording is required.

Let us examine one more compensation circuit (Fig. 3) which consists of a cascade connection of two autocompensator circuits. This circuit is useful for measuring small voltages with an accuracy equal to the best measuring devices and with direct reading. If a single compensation circuit were used it would have been necessary to have a highly sensitive device with a small internal resistance in order to have a sufficiently large feedback factor β_2 without making the gain too high. Hence in order to improve the stability of the circuit and use a rougher voltage adjustment and therefore make the compensator more reliable and accurate it is desirable to divide the amplification between two or more stages which are not interconnected by a common feedback.

The input of the second autocompensator is fed with a voltage greater than the measured emf by a factor of $\underline{k} = R_0/R'$ and hence factor β_2 can be made in this instance sufficiently large even with a relatively high output resistance.

The output currents of the first and second compensators are:

$$I_2'=\frac{e}{R'\left(1+\frac{1}{\beta_1'\beta_2'K_\infty'}\right)};\quad I_2''=\frac{I_2'R_0}{R''\left(1+\frac{1}{\beta_1''\beta_2''K_\infty''}\right)}.$$

The sensitivity of the double compensator is:

$$S_{dac} = \frac{\partial\alpha}{\partial e} = \frac{R_0 S_i}{R' R''\left(1+\frac{1}{\beta_1'\beta_2' K_\infty'}\right)\left(1+\frac{1}{\beta_1''\beta_2'' K_\infty''}\right)}. \quad (11)$$

It follows from (11) that with $K_\infty' \gg 1$ and $K_\infty'' \gg 1$ the sensitivity of the double autocompensator increases as compared with that of the output compensator by a factor of $k = R_0/R'$.

The limit to which the sensitivity of the circuit can be increased is determined by the zero drift and the noise in the first autocompensator.

If the input current i_0 corresponding to the zero drift is known, it is easy to find the voltage u_0 at the input of the second autocompensator caused by this current [7]:

$$u_0 = \frac{i_0 R_0}{\beta_1 \beta_2 K_\infty}.$$

It will be seen from this equation that in order to increase the effective sensitivity of the double compensator circuit it is necessary to select the parameters of the first autocompensator in such a manner that factor $(\beta_1\beta_2K_\infty)$ is as large as possible.

The error of the double autocompensator is:

$$\delta_{dac} = \frac{\partial S_{dac}}{S_{dac}} = \frac{\partial R_0}{R_0} + \frac{\partial R'}{R'} + \frac{\partial R''}{R''} + \frac{\partial S_i}{S_i} + \frac{\frac{\partial\beta_1'}{\beta_1'} + \frac{\partial\beta_2'}{\beta_2'} + \frac{\partial K_\infty'}{K_\infty'}}{1+\beta_1'\beta_2'K_\infty'} + \frac{\frac{\partial\beta_1''}{\beta_1''} + \frac{\partial\beta_2''}{\beta_2''} + \frac{\partial K_\infty''}{K_\infty''}}{1+\beta_1''\beta_2''K_\infty''}. \quad (12)$$

It will be seen from (12) that if the conditions $\beta_1'\beta_2'K_\infty' \gg 1$ and $\beta_1''\beta_2''K_\infty'' \gg 1$ hold and resistance R_0, R' and R" are accurate the error of a double autocompensator is determined in practice by the error of the output instrument.

The input resistance of the circuit is equal to that of the first autocompensator.

Contrary to the circuit in Fig. 2 the cascade autocompensator does not require a standard cell, but it cannot give the same accuracy of measurement as the circuit with a controlled resistance compensator output.

Tests of the double cascade compensator circuits produced satisfactory results.

The possible combinations of compensators with controlled resistance and controlled current are not limited to two stages. Similarly to formulas (11) and (12) it is possible to obtain expressions for sensitivity and errors for n stages. Thus:

$$S_n = \frac{S_i \prod_{p=1}^{p=n-1} k_p}{R^{(n)} \prod_{q=1}^{q=n} N_q}, \quad (13)$$

where S_i is the sensitivity of the output instrument; $k_p = (R_0/R)_p$ is the voltage transfer constant of the p-th cascade

$$N_q = \left(1+\frac{1}{\beta_1\beta_2K_\infty}\right)_q; \quad \delta_n = \sum_{l=1}^{l=n-1}\left(\frac{\partial R_0}{R_0}\right)_l + \sum_{l=1}^{l=n}\left(\frac{\partial R}{R}\right)_l + \sum_{l=1}^{l=n}\left(\frac{\partial N}{N}\right)_l + \frac{\partial S_i}{S_i}. \quad (14)$$

Expressions (13) and (14) lead to the conclusion that under certain conditions the sensitivity of the cascade autocompensator can be considerably higher than that of a single autocompensator, and that its error is practically equal to that of the output measuring instrument. It is however necessary to take into account the zero drift and the noise in the first autocompensator.

Three cascade compensators with a combination CRC–CIC–CRC and CIC–CIC–CRC are of interest.

On the basis of the above it is possible to conclude that the use of double and cascade compensation circuits

provides measuring devices with a number of important advantages: increased sensitivity and accuracy of measurement, a higher input resistance, speedier measurements and an increased stability.

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ERROR OF MEASURING THE MEAN VOLTAGE VALUE WITH A MECHANICALLY RECTIFYING METER

N. V. Levitskaia

In measuring practice it is often required to measure the mean value of voltage both of a pure sinusoidal form and one highly distorted by harmonics. Such a problem arises, for instance, in determining the parameters of circuits containing iron. These measurements can be made by means of rectifying instruments consisting of a moving coil meter, connected in series or in parallel with a phase-controlled mechanical rectifier. The contacts of the latter during a given part of the period are closed and during the rest of the period – open.

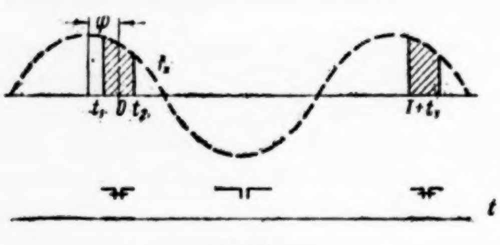

Fig. 1.

In a series connection of the mechanical rectifier with the measuring instrument, current with flow through the latter only when the contacts are closed. The instrument will then record the mean current flowing though it during the make periods.

According to the general theory of vector measuring instruments [1] the mean value of the p-th harmonic current flowing through the measuring instrument is equal to:

$$I_{av} = \frac{U_m}{p\pi}(y_1 - y_2)\sin\frac{p\pi}{n}\cos\psi, \tag{1}$$

where U_m is the maximum value of the measured voltage:

$$U_x = U_m \cdot \cos(p\omega t + \psi).$$

$\omega = 2\pi/T$ is the angular velocity of the measured voltage; y_1) the mutual conductance between the measured voltage U_x circuit and that of the measuring instrument which exists during a certain portion T/n of each period; y_2 is the mutual conductance between the measured voltage circuit and that of the measuring instrument which exists during the remaining portion $(n-1/n)T$ of the period.

The datum line for reckoning is taken as the middle of the time interval t_1t_2 corresponding to the mutual conductance y_1 (Fig. 1) so that $t_1 = -T/2n$ and $t_2 = +T/2n$.

In mechanical rectifiers mutual conductance y_2 is determined by the leakage across the open contacts, and approaches zero.

Mutual conductance y_1 is determined by the conductance of the measured voltage circuit with closed contacts of the mechanical rectifier.

The error of the mechanically operated rectifier consists of the error of the measuring instrument used, the eror due to the mechanical rectifier and the error in determining the values of conductances y_1 and y_2 and their instability.

The error of the measuring instrument can have different values according to the grade of instrument used and in general has a random nature.

The instability of the periodic process of closing and opening contacts which causes errors of measurement, is determined by a combination of a number of reasons which are also of a random character.

The random error introduced by conductance y_2 is due to the variations in the leakage between the mechanical rectifier contacts.

The random error introduced by conductance y_1 is due to the instability of the measured circuit resistance including that of the mechanical rectifier contacts.

According to the law of adding random errors* the error of measuring the mean current value is:

$$\frac{\Delta I_{av}}{I_{av}} = \sqrt{\left(\frac{\Delta n}{n}\right)^2\left(\frac{p\pi}{n}\right)^2 \mathrm{ctg}^2\left(\frac{p\pi}{n}\right) + \left(\mathrm{tg}\psi\right)^2\left(\sin\Delta\psi\right)^2 + \left[\frac{\Delta(y_1-y_2)}{y_1}\right]^2 + a^2}, \qquad (2)$$

where Δn is the error in the commutation duration; $\sin\Delta\psi \approx \Delta\psi$ is the phase error of the meter (the error of the making contact phase of the mechanical rectifier); a is the relative error of the measuring instrument; Δy_1 and Δy_2 are errors in conductances y_1 and y_2.

The first two terms of the expression under the radical in (2) are particular errors of measurement of the mean current value due to the errors in the phase ψ and duration $1/n$ of the closing of the contacts. They will reach a minimum $\psi = 0$ (maximum deflection of the measuring instrument) and at the relative duration of making $1/n = 1/2p$.

The permissible errors of the instrument are usually referred to the fundamental ($p = 1$) at $1/n = 1/2$ and $\psi = 0$. The vector-measuring device, however, can measure at $\psi \neq 0$ and $1/n \neq 1/2p$. In such cases the limiting error of measurement can be determined from (2) if the quantities Δn, $\Delta\psi$, a and $\Delta(y_1-y_2)$ are known. In testing it is necessary to find these discrete errors and determine their relation to the error of the mean current value measurement.

As an example let us examine the errors of the vector measuring device Ts-50 made by the Kiev "Tochelectropribor" plant. The principle of operation of the instrument is obvious from Fig. 2.

The vector meter will operate both with a built-in instrument grade 1.0 or with an external instrument grade 0.5.

The excitation winding of the mechanical rectifier synchronous motor is fed from the same source as the measured current. The rectifier contacts are opened in synchronism with the motor supply frequency by a cam fixed to the axle of the motor (Fig. 2).

*In this instance it is advisable to take instead of mean errors "limiting" ones which equal to 3σ, where σ is the mean square error.

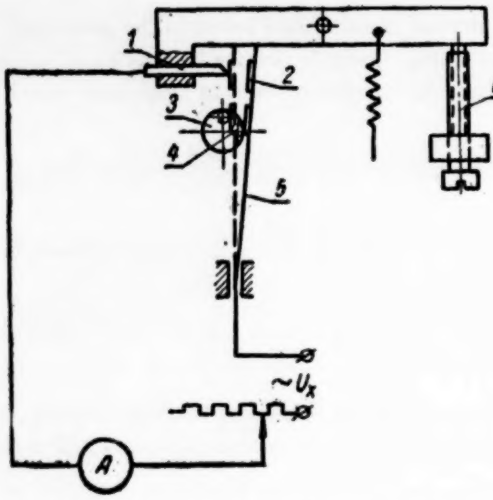

Fig. 2. 1) Setting contact; 2) moving contact; 3) synchronous motor axle; 4) cam; 5) contact spring; 6) screw for setting duration of making.

Adjustment of the setting contact changes the relative duration of making and the rotation of the whole contact assembly changes the instant of breaking, i.e., changes angle ψ.

The error in the relative contact making time $\Delta n/n$ is determined by the inaccuracy of setting and variations in the duration of making during operation. The latter is due to several reasons and in the first instance to the variations in the angular velocity of the synchronous motor caused by slipping or friction of the mechanical system of the rectifier, contact vibrations, changes in the travel of the moving contact owing to acquired irregularities on the contact spring pad surface, over which the cam slides, and to play in the motor axle bearings.

It should be noted that the contact spring pad is made of a soft material in order to reduce the contact vibration error. If the material of the pad is incorrectly selected or the conditions of operation are unsuitable, strains in the pad surface may affect considerably the accuracy of measurement.

The effect of the instability of the contact making time on the reading of the measuring instrument can be determined experimentally by measuring with the vector-meter a direct current of a given constant value at a contact making time equal to half a period.

In this instance the instability of the contact making time will cause irregular oscillations of the measuring instrument pointer. The swing of these oscillations (in fractions of the scale length) can serve as a measure of the error of current measurement due to the instability of the contact making time.

The error of a given adjustment with respect to the contact making time can be determined in the following manner.

When the required contact making time is set, the measuring instrument is connected in series with a battery, the setting resistor and the mechanical rectifier. At first the contacts are shorted and the current is set to the upper limit of the instrument scale. Next the rectifier is energized and the contacts set in motion. Then the reading of the instrument is decreased and becomes equal to the mean value of the current flowing through the instrument.

The required contact making time is then obtained by appropriate adjustment:

$$\frac{1}{n}=\frac{I_{av}}{I},$$

where I is the current flowing through the measuring instrument when the contacts are shorted; I_{av} is the current flowing through the measuring instrument when the contacts are operating.

In fact the value of I is set with an error ΔI, due in the main to the error of the measuring instrument. The value of I_{av} is actually set with an error ΔI_{av} due to both the error of the instrument and that of the instability of the contact making time.

The relative error of the contact making time setting is

$$\varepsilon=\sqrt{\left(\frac{\Delta I_{H}}{I_{H}}\right)^2+\left(\frac{\Delta I_{av}}{I_{av}}\right)^2}.$$

Considering that I_H corresponds to the upper limit of the instrument scale, it can be considered that the

limiting error of measurement $\Delta I/I$ will be determined by the permissible error of measurement $\underline{a}$ for instruments of the grade used, i.e.,

$$\frac{\Delta I}{I} = a.$$

In turn

$$\frac{\Delta I_{av}}{I_{av}} = \frac{\Delta I_{av}}{I_{н}} \frac{I_{н}}{I_{av}} = n\sqrt{a^2 + c^2},$$

where $\underline{c}$ is the limiting permissible variation in the reading of the measuring instrument due to the instability of the mechanical rectifier operation (in fractions of the scale length). Then:

$$\varepsilon = \sqrt{a^2 + a^2n^2 + c^2n^2}.$$

The resulting limiting error of the contact making time due to the instability of operation and inaccuracy of setting is

$$\frac{\Delta n}{n} = \sqrt{(a^2 + c^2)\ (1 + n^2)} \tag{3}$$

The phase error of the rectifier depends on the accuracy of setting and stability of the phase of the contact making time.

In the rectifier Ts-50 the contact making time is set by adjusting to zero ($\psi = \pi/2$) and then rotating the contact assembly through the required angle by means of the calibrated contact adjusting head.

The error in setting the phase is determined in the main by the error of zero setting and the error of reading the adjusting head calibrations as well as the difference between the phase shift and the angle of rotation of the assembly due to the instability of operation of the mechanical rectifier and in particular to the variations in the motor angular velocity. The remaining reasons for the instability of operation of the mechanical rectifier are in the main the same as those already pointed out before.

The phase error of the rectifier can be most simply determined experimentally by means of a standard ac potentiometer and an auxiliary phase shifter.

For this test, the rectifier, the ac potentiometer supply circuit and the phase-shifter primary coil are all connected to the same ac supply. Voltage U_x obtained on the secondary of the phase shifter is measured by means of the ac potentiometer and the rectifier under test. For simpler adjustment, voltage U_x is first set to coincide in phase with the potentiometer supply voltage and the zero is set on the rectifier scale. Next the phase of U_x is changed by a certain angle ψ which is measured by means of the standard ac potentiometer and the vector-meter under test. The phase error of the vector-meter is determined by the difference in the measurement of the angle obtained by it and the potentiometer.

Errors Δy_1 and Δy_2 can be determined by known means. Usually in correctly constructed instruments these errors are small. Hence if the permissible errors $\underline{a}$, $\underline{c}$ and $\Delta\psi$ are determined or obtained experimentally for any given vector-meter, the limiting current measuring error can be generally determined from the formula:

$$\frac{\Delta I_{av}}{I_{av}} = \sqrt{a^2 + [(n^2 + 1)\ (a^2 + c^2)]\left(\frac{p\pi}{n}\right)^2 \mathrm{ctg}^2\left(\frac{p\pi}{n}\right) + (\mathrm{tg}\,\psi)^2\ (\Delta\psi)^2}. \tag{4}$$

This error can be determined experimentally by comparing the readings of the vector-meter with those of a standard instrument (for instance an electrodynamic instrument) on an alternating current. In this connection the effect of the shape of the measured current wave on the readings of the vector-meter should be taken into account.

In addition to above mentioned sources of errors, which will be present to a certain extent in all mechanical vector-meters, it is necessary to mention one more possible error, that due to electromechanical natural resonance of the moving parts of the instrument at harmonic frequencies of the rectified current flowing through the meter.

In this instance large random oscillations of the measuring instrument pointer will be observed and will interfere with measurements. This becomes especially pronounced when the contact making time differs from a half period of the supply frequency. The shape of the current wave in this instance will be distorted to such an extent that it will be easily seen on an oscillograph screen.

In a correctly constructed instrument these phenomena should not be present.

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MEASUREMENT OF SMALL PHASE ANGLES BY MEANS OF A CATHODE-RAY TUBE

A. I. Iudin

Cathode-ray tubes are normally used for measuring phase differences between two voltages of the same frequency. If one of the voltages is fed to the horizontal and the other to the vertical deflecting plates of the tube, an elliptical figure will be produced whose parameters are determined by the relation of the phases and amplitudes of the applied voltages. It is thus possible to determined the required phase difference by the geometrical configuration of the ellipse [1, 2 and 3].

When small phase angles are measured (or when they are close to 180°) the minor axis of the ellipse and lengths AA' and CC' (Fig. 1) tend to zero and can become even thinner than the trace, which makes the measurements very inaccurate or even completely impossible.

The accuracy of measurement of small angles can be greatly increased if one of the plates is fed with a voltage of a frequency n times higher than the other [4].

The object of the present article is the evolving of basic relations and quantitative estimation of errors obtained in measurements by this method.

Let a sinusoidal voltage be applied to the vertically deflecting plates of an oscillograph:

$$u_1 = U_1 \sin(\omega t + \varphi), \tag{1}$$

and to the horizontal plates a voltage:

$$u_2 = U_2 \sin n\omega t, \tag{2}$$

where φ is the initial phase difference and n is a positive integer.

The ordinate of the figure on the oscillograph screen is equal to:

$$y = m_1 U_1 \sin(\omega t + \varphi), \tag{3}$$

and the abscissa to:

$$x = m_2 U_2 \sin n\omega t. \tag{4}$$

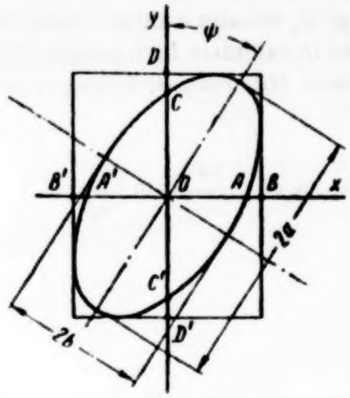

Fig. 1.

Here m_1 and m_2 are the sensitivities of the corresponding plates of the cathode-ray tube.

Let us find the points at which the trace crosses the y axis.

From (4) at x = 0 we have:

$$n\omega t = k\pi, \tag{5}$$

where k = 0, 1, 2,...

Whence

$$\omega t = \frac{k\pi}{n}. \tag{6}$$

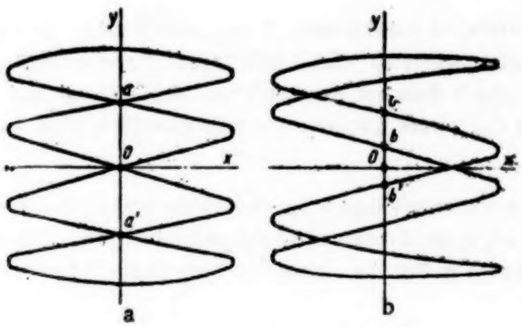

Fig. 2.

Substituting (6) in (3) we obtain the required values of y which correspond to the points where the figure crosses the y axis:

$$y_k = m_1 U_1 \sin\left(\frac{k\pi}{n} + \varphi\right). \tag{7}$$

Obviously the number of points at which the figure crosses the y-axis is equal to 2n. Figure 2 shows images with n = 4 and varying phase differences between voltages u_1 and u_2.

The distance between two symmetrical points where the figure crosses the y axis is:

$$y_k - y_{k+n} = m_1 U_1 \sin\left(\frac{k\pi}{n} + \varphi\right) - m_1 U_1 \sin\left[\frac{\pi(k+n)}{n} + \varphi\right] = 2m_1 U_1 \sin\left(\frac{k\pi}{n} + \varphi\right). \tag{8}$$

Assuming k = 0,

$$y_0 - y_n = 2m_1 U_1 \sin\varphi. \tag{9}$$

Substituting $\varphi = 0$ in (8) we obtain:

$$y'_k - y'_{k+n} = 2m_1 U_1 \sin\frac{k\pi}{n}. \tag{10}$$

From (9) and (10) we have:

$$\sin\varphi = \frac{y_0 - y_n}{y'_k - y'_{k+n}} \sin\frac{k\pi}{n}, \tag{11}$$

It is easily checked that all the crossing points of the figure at $\varphi = 0$ lie on the y axis (Fig. 2a).

This suggests an easy method of determining the position of the y axis. In order to orientate the figure along the coordinates when $\varphi = 0$ it is sufficient to make the crossing points of the figure coincide with the y axis and place the center of the figure at the origin. When measuring (with $\varphi = 0$) it is convenient to consider the two symmetrical points where the figure crosses the y axis nearest to the origin (points aa' in Fig. 2a).

Point a corresponds to k = 1 and point a' to k = 1 + n = 5.

Points $y_{k=0}$ and $y_{k=n}$ when $\varphi = 0$ coincide with the origin of the coordinates.

If $\varphi \neq 0$, points $y_{k=0}$ and $y_{k=n}$ are displaced from the origin (points b and b' in Fig. 2b).

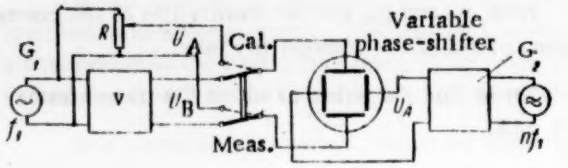

Fig. 3.

If voltage U_1 remains constant during the measurement, it is easy to calculate from lengths aa' and bb' the required phase difference by writing expression (11) in the form:

$$\sin\varphi = \frac{bb'}{aa'}\sin\frac{\pi}{n}. \tag{12}$$

And at large values of n:

$$\varphi \approx \frac{bb'}{aa'}\cdot\frac{\pi}{n}. \tag{13}$$

Points a and a' as well as b and b' are placed symmetrically with respect to the origin of the coordinates, hence it is possible to replace them with Oa and Ob. This makes it possible to extend one loop to the whole screen of the oscillograph in order to raise the accuracy of determining the required angle.

In order to determine by above means the phase characteristic of a quadripole X the circuit shown in Fig. 3 is suitable. With generator G_2 disconnected switch S is thrown alternately to "Cal." and "Meas." and an equal deflection amplitude is obtained by means of potentiometer R (which does not introduce any phase distortion). Next the switch is thrown into the "Cal." position and generator G_2, whose frequency is n times higher than that of generator G_1, is switched in.

When the frequency of generator G_2 is adjusted to obtain a stationary figure on the oscillograph, the initial phase difference of zero between voltages of frequencies f_1 and nf_1 is set by means of the phase-shifter. This will produce a figure on the oscillograph screen similar to the one shown in Fig. 2a. Now one loop of the figure can be extended to the whole screen and distance aa' measured.

Following this operation the switch is thrown to position "Meas." and the length bb' is measured. The required phase angle difference between the input and the output of the quadripole is found from Eq. (12) or for large n from Eq. (13). If n = 12, the error introduced when using Eq. (13) does not exceed 10'.

Above operative formulas have been derived with the assumption that the voltages at the input and output of the quadripole are the same. If voltages U_A and U_B (Fig. 3) are not equal, the phase difference determination from (12) or (13) will lead to inaccuracies. Let voltages U_A and U_B differ by ΔU, then the lengths between crossing points produced on the oscillograph screen will be:

$$aa' = 2m_1U_1\sin\frac{\pi}{n},$$
$$bb' = 2m_1(U_1+\Delta U)\sin\varphi.$$

Substituting these values in (12) we obtain:

$$\sin(\varphi+\Delta\varphi) = \frac{U_1+\Delta U}{U_1}\sin\varphi. \tag{14}$$

After trigonometrical transformations we shall obtain the error due to the difference between voltages U_A and U_B as:

$$\Delta\varphi \approx \pm\frac{\Delta U}{U_1}\operatorname{tg}\varphi. \tag{15}$$

It is possible to determine the phase difference between the input and the output voltages of the quandripole without equating U_A to U_B.

For this instance it can be shown that

$$\varphi \approx \frac{bb'}{cb'}\ \frac{\pi}{2n}\ \text{(see Fig. 2b).} \tag{16}$$

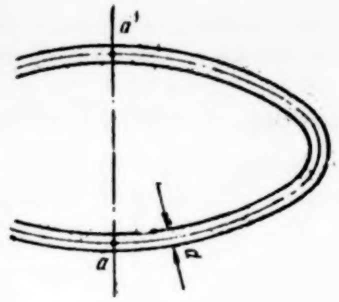

Fig. 4.

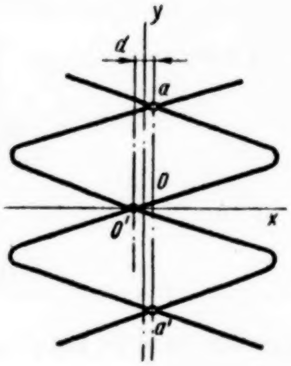

Fig. 5.

In addition to the errors due to the inequality of the measured voltages there is also the error due to the thickness of the trace on the screen. The spot diameter on the majority of the oscillographs can be made equal to 0.5-1 mm.

It will be seen from Fig. 4 that the distance between two points of the image can be estimated with an accuracy of ± d, where d is the thickness of the trace, which is equal to the spot diameter.

The lengths aa' and bb' will be determined with an accuracy of ± d.

For instance when the phase difference is calculated by means of formula (13)

$$\varphi_{max} \simeq \frac{bb'+d}{aa'-d} \cdot \frac{\pi}{n}, \tag{17}$$

$$\varphi_{min} \simeq \frac{bb'-d}{aa'+d} \cdot \frac{\pi}{n}. \tag{18}$$

The difference between these expressions is equal to:

$$2\Delta\varphi = \varphi_{max} - \varphi_{min} = \left(\frac{bb'+d}{aa'-d} - \frac{bb'-d}{aa'+d}\right)\frac{\pi}{n} \tag{19}$$

hence

$$\Delta\varphi \simeq \frac{d}{aa'}\left(1+\frac{n\varphi}{\pi}\right)\frac{\pi}{n} \tag{20}$$

From the last expression it is possible to find the limits of the variations of $\Delta\varphi$.

Since $0 \leq \varphi \leq \pi/n$,

$$\frac{\pi}{n} \cdot \frac{d}{aa'} < \Delta\varphi < 2\,\frac{\pi}{n} \cdot \frac{d}{aa'}. \tag{21}$$

If the screen diameter is equal to 125 mm, it is possible to obtain a length aa' equal to some 100 mm. With a spot diameter of d = 1 mm and an n = 12 we obtain

$$\Delta\varphi < 18',$$

which is completely satisfactory in many instances.

Another source of errors can be the inaccurate setting of the zero phase difference between the voltages at the input of the measured quadripole and the voltage of generator G_2. In the case of an inaccurate zero adjustment the figure crossing points will not fall on the y axis but will be placed in a zigzag line with respect to it (Fig. 5). The inaccurate setting of zero is determined and limited by the thickness of the trace. Thus the position of the vertical axis can be determined with the accuracy of ± 0.5 d. This in turn means that the lengths aa' and bb' required for finding the phase angle will be determined with a certain error δ.

It will be seen from Fig. 5 that point O' has the coordinates:

$$x = -\frac{d}{2}, \quad y = 0.$$

Substituting these values in (3) and (4) we obtain:

$$0 = m_1 U_1 \sin(\omega t + \varphi_0), \tag{22}$$

$$-\frac{d}{2} = m_2 U_2 \sin n\omega t. \tag{23}$$

From (22)

$$\omega t = k\pi + \varphi_0, \tag{24}$$

where k = 0, 1, 2,... and φ_0 is the initial phase difference due to inaccurate zero setting.

Substituting the value of ωt in (23) we have:

$$\frac{d}{2} = - m_2 U_2 \sin n\,(k\pi - \varphi_0)\,.$$

which gives for the initial point of the curve (k = 0):

$$\frac{d}{2} = m_2 U_2 \sin n\,\varphi_0\,. \tag{25}$$

Whence it follows that the initial phase difference corresponding to distance d/2 is equal to:

$$\varphi_0 \simeq \frac{d}{2nm_2U_2}\,. \tag{26}$$

Let us now find the length aa' = $2y_{k=1}$ from (7) at $\varphi = \varphi_0$ and k = 1.

$$aa' \simeq 2m_1U_1 \sin\left(\frac{\pi}{2} + \frac{d}{2nm_2U_2}\right). \tag{27}$$

This value of aa' differs from its value of $\varphi_0 = 0$ by the quantity δ which is equal to: (see (10) and (27))

$$\delta = 2m_1U_1 \sin\left(\frac{\pi}{n} + \frac{d}{2nm_2U_2}\right) - 2m_1U_1 \sin\frac{\pi}{n} \simeq \frac{dm_1U_1}{nm_2U_2}\cos\frac{\pi}{n}\,. \tag{28}$$

Since in practice $m_1 \approx m_2$ and $U_1 \approx U_2$ and the limiting value of cos π/n is unity we have:

$$\delta < \frac{d}{n}\,. \tag{29}$$

Formula (13) can be made more accurate:

$$\varphi' = \frac{bb' \pm \delta}{aa' \pm \delta} \cdot \frac{\pi}{n}\,. \tag{30}$$

In order to determine the error due to the an inaccurate initial setting of the zero phase let us find the difference between expressions (30) and (13):

$$\Delta\varphi' = \frac{bb' \pm \delta}{aa' \pm \delta} \cdot \frac{\pi}{n} - \frac{bb'}{aa} \cdot \frac{\pi}{n} \simeq \pm \frac{\delta}{aa'} \cdot \frac{\pi}{n}\,. \tag{31}$$

Let us substitute δ in the obtained expression:

$$\Delta\varphi' < 2\frac{\pi}{n} \cdot \frac{d}{aa'} \cdot \frac{1}{2n}\,. \tag{32}$$

From the comparison of expressions (32) and (21) it will be seen that the error of measurement due to an inaccurate zero setting does not exceed that due to the thickness of the trace.

It should be noted that for angles of φ and $\varphi + \pi/n$ the figures on the oscillograph screen have the same appearance. Hence before measuring it is necessary to ascertain that angle $\varphi < \pi/n$. For this purpose it is possible to feed voltages U_A and U_B respectively to mutually perpendicular deflecting plates in the usual manner and thus determine the approximate phase difference.

The determination of the phase difference by above means is connected with the requirement of keeping exact harmonic relation between the frequencies of the measuring and auxiliary generators. This creates certain

difficulties when measuring over a wide band of frequencies, since in passing from one frequency to another it becomes necessary to readjust the auxiliary generator. This defect can be remedied by synchronizing the generators. With a small number of measured frequencies it is best to use a frequency multiplier instead of an auxiliary generator.

A variable phase shifter, which is only required for setting the zero, can be made without great difficulties. The design of the simplest phase-shifters is given in [2].

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HIGH AND ULTRA-HIGH FREQUENCY MEASUREMENTS

ERRORS IN STANDARD DEVICES FOR MEASURING FIELD STRENGTH IN THE 30 TO 600 MC BAND

A. A. Kotovich

According to the 1946 recommendations of the International Scientific Radio Association measurements of field strength in the 30 to 600 Mc band should have errors not exceeding ± 5 to 10% [1]. For meeting above requirements certain methods of measuring and equipment are required.

It is possible to find many papers dealing with this question in the technical literature both at home and abroad. However most of them deal with the design of instruments without strict requirements of accuracy and precision [2, 3 and 4]. Only in the fairly recently published papers [5 and 6] any attempts are made to justify the methods of measurement and calculation of errors in the above band of frequencies.

In the main two methods are used for measuring field strength of electromagnetic waves: the method of the standard antenna and that of the standard field, which we shall call the method of a reference antenna and reference field [4].

The method of the reference antenna is based on the known relation between the voltage E of the electromagnetic wave and the emf E_α induced in the receiving antenna:

$$|\dot{E}| = \frac{E_a}{l_\partial} . \tag{1}$$

where l_∂ is the effective length of the antenna.

All the formulas are given here in the practical system of units.

In the reference field method the relation between the field strength established in a given point by a radiator of a given geometrical shape and current I in the radiator can be represented by the following general expression:

$$E = F(I, \lambda, l_\partial, R, W, d), \tag{2}$$

where l_∂ is the effective length of the radiating antenna; W is the attenuation coefficient of the ground wave [7] and $\underline{d}$ is the distance from the radiator.

In theory the method of a reference antenna and that of the reference field should give the same results in field strength measurements according to the principle of the reversibility of transmitting and receiving antennas [8]. This property is widely used in the measurement techniques for checking the accuracy and precision of measurements: the results obtained by different methods are thus compared. This comparison provides a measure of systematic errors which cannot be calculated, for instance, errors due to feeders, the difference in the transmitting and receiving antennas' connections, that caused by surrounding objects, unevenness of the ground surface and other reasons. Above mentioned reversibility properties are also used for [6] making basic field strength measuring instruments.

By comparing (1) and (2) it is possible to deduce that the reference antenna method is simpler than the reference field method. Its advantage consists in the possibility of determining the field strength without the knowledge of the ground parameters, the exact distance between the transmitting and receiving antennas, or the parameters of the transmitting antenna.

However, these advantages can be used and have any meaning in the checking technique only if correct fields are established my means of standard instruments. In basic or standard instruments these advantages of one method over the other have no meaning, since both methods being considered of equal value are used in appropriate tests for finding and eliminating systematic errors. Therefore it is advisable to examine both methods and draw the required conclusions about the possible errors of measurement.

Reference Antenna Method. In this method the total field strength measurement error consists of the error of measuring the induced emf and calculating the effective length of the antenna.

The error of the emf measurement depends in the first place on the relation between the antenna impedance Z_a and that of the load Z_l ohms, input of crystal rectifier or thermal detector). The field strength according to (1) is equal to:

$$E = \frac{I_a Z_l + I_a Z_a}{l_\partial}, \tag{3}$$

where $I_a Z_l + I_a Z_a = E_\alpha$.

In order to be able to determine the error of measurement of the emf it is necessary to know Z_a and Z_l or to measure with $Z_l \gg Z_a$. Then the knowledge of Z_a alone is required.

In the frequency range under consideration the antenna impedance cannot be determined with an error below 5-10%. Moreover the necessity of measuring the impedance of the antenna and the load considerably complicates the measurement method. It is therefore better to make such tests under the conditions of $Z_l \gg Z_a$. The fulfilment of this condition also decreases the error due to the effect of the ground parameters on those of the antenna.

If a crystal rectifier voltmeter is used for measuring the emf in the receiving antenna, [6] the relation $Z_l \gg Z_a$ can be maintained up to 300 Mc. The error introduced by the load into the measurement results is of the order of tenths of a percent.

At higher frequencies this relation no longer holds since impedance Z_l decreases [9]. At higher frequencies the measurement of the induced emf is made by means of thermal detectors, which can be used for measuring field strength up to 1,000 Mc [5].

In order to increase the accuracy of measurement of the rectified current dc component or the thermal emf of the detector a potentiometer is used. In this instance the emf induced in the antenna can be measured with an error not exceeding 2% at $E \approx 10$ mv/m to 1 v/m.

The second component of the measurement error in the reference antenna method is due to inaccuracies in calculating the effective length of the antenna. Of the two types of reference antennas used, the horizontal and vertical dipoles, the former is preferred for the following reasons. The field strength established at relatively short distances from the transmitting antenna depends on the type of the antenna (the distances in this case do not exceed 10 to 50 λ). Analysis has shown [7, 10 and 11] that the field strength can be determined more accurately for a horizontal dipole raised above ground than for a vertical one. This is due to the ground wave component of a horizontal dipole becoming negligibly small at lower frequencies and at smaller dipole heights than that of a vertical dipole. Moreover with horizontal polarization the modulus of the complex reflection coefficient of the electromagnetic waves from gound $|\dot{R}|$ reaches a value close to unity and the angle Θ approaches π, at higher angles of elevation than with vertical polarization [7]. For those reasons in the majority of cases horizontal half-wave dipoles are used.

The calculation in a general form of the effective length of a half-wave dipole is a complicated problem and the expression obtained is difficult to use for design purposes [12 and 13]. It is much simpler to solve this problem is parts. At first a half-wave receiving dipole in open space is calculated, with the assumption that the existence of the transmitting dipole and ground does not effect the current distribution in the receiving dipole [14, 15]; next the conditions are determined for which the effect of above factors can be neglected, i.e., conditions for which the calculated results obtained for a dipole in open space are correct with a given error for a space limited by a flat ground and a transmitting dipole.

In open space the effective length l_∂ of a cylindrical dipole with radius $\underline{r}$ and length $2l$ is [6]:

$$l_d = \frac{\lambda}{\pi}(1 + \Delta l_1)(1 - \Delta l_2), \quad (4)$$

where Δl_1 is the relative increment in the half-wave dipole effective length which depends on the equivalent dipole impedance

$$\rho_v = 120\left(\ln\frac{2l}{r} - 1\right),$$

and Δl_2 is the relative decrement in the half-wave dipole required in tuning the dipole for resonance with the frequency of radiated oscillations [14].

If the above corrections are taken into account the antenna effective length can be calculated with an error of the order of 0.5%.

For actual working conditions of the dipole the calculation is approximate owing to the presence of other sources of error. The basic sources are the gap between the two halves of the receiving dipole, and the ground effect.

The opinion of various authors and experimental results differ with respect to the first source of errors. In [14 and 16] it is stated that the dipole parameters depend to a great extent on the value of the gap, but in [6] that it does not affect the parameters. Since opinions on this matter differ it must be regarded as an open question and conclusions should be drawn according to the experimental results obtained.

A precise account of the effect of the transmitting dipole on the receiving one has been given by various authors. The expressions obtained for this effect are too complicated for design purposes [17], but they can be considerably simplified if the distance d between the dipoles is fixed at not less than two wavelengths [18]. Then the value of the additional impedance will be:

$$Z \simeq j\frac{60\lambda}{\pi d} e^{-j2\pi d/\lambda}. \quad (5)$$

The error introduced in the final result of the field strength measurement when the approximate formula (5) is used does not exceed tenths of one percent [19].

The effect of ground on the dipole parameters can be calculated accurately but only by means of complicated and cumbersome formulas. It is, however, impossible to correct for these errors since the ground parameters, its relative permittivity ϵ' and conductance σ, depend to a great extent on meteorological conditions. Hence it is preferable to determine the extent of this error and find the conditions for which it can be neglected.

The calculation of the field strength measuring error is made for various ground parameters, for an ideally conducting ground $\sigma = \infty$; for a moist ground $\sigma = 10^{-2}$ 1/ohm · m, $\epsilon' = 10$ and for dry ground $\sigma = 10^{-3}$ 1/ohm · m, $\epsilon' = 4$.

The error can be evaluated from the following approximate formula [19]:

$$\delta \simeq \left(\left|\frac{Z_l + Z_{33}}{Z_l + Z_{33} + \dot{R}_1 Z_{34}}\right| - 1\right) \cdot 100\%, \quad (6)$$

where Z_l is the load impedance, ohms (of the input of the crystal rectifier or thermal detector); Z_{33} is the impedance of the half-wave dipole in open space; $Z_{33} = 73.2 + j\,42.5$ ohms [14]; Z_{34} is the value of the impedance introduced by the presence of ground when the dipole is at a height above ground of $h \geq \lambda$,

$$Z_{34} \simeq j\frac{30\lambda}{\pi h} e^{-j4\pi h/\lambda} \text{ ohm},$$

and $\dot{R}_1$ is the reflection coefficient of the field from ground in a vertical direction. In the frequency range under consideration it can be considered that $\dot{R}_1 = |\dot{R}|$ [6].

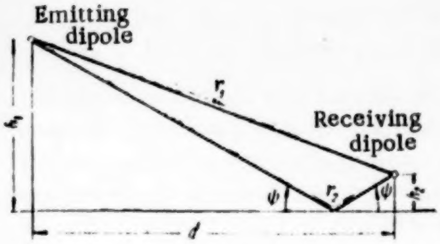

Fig. 1. Schematic of radio wave propagation over a flat ground. r_1 is the direct beam; r_2 is the beam reflected from ground; d is the distance between the dipoles; h_1 and h_2 are respectively the heights of the transmitting and receiving dipoles above ground.

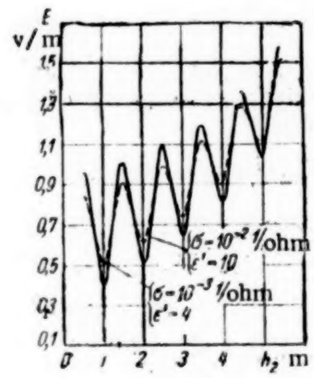

Fig. 2. Relation between the field strength and the height of the receiving dipole h_2.

The ideally conducting ground has the largest effect on the dipole parameters. In this instance with a Z_l = 73 ohms the error in the field strength measurement attains 10% (h/λ = 0.65). In the case of damp ground the error decreases to 5.5% and for dry ground to 2.6%.

The error is considerably reduced if the load impedance Z_l is increased.

Thus if Z_l = 300 ohms the error in measuring the field strength with a damp ground decreases to 2.5%.

In order that the error should not exceed 1% under the above conditions the height of the dipole above ground should not be less than the wavelength to which the dipole is tuned, i.e., $h/\lambda \geq 1$.

The Reference Field Method. The field strength in the frequency range under consideration is determined from the "reflection formula" [6, 7 and 20].

The effective field strength established by a horizontal half-wave dipole (Fig. 1) in the direction of a perpendicular drawn to the center of the dipole and at distances exceeding 2λ is equal to:

$$\dot{E} \,\Big|\simeq \frac{60\pi I l_\partial}{\lambda} \left| \frac{e^{-j2\pi r_1/\lambda}}{r_1} + \frac{\dot{R}e^{-j2\pi r_2/\lambda}}{r_2} + \dots \right|. \quad (7)$$

The points in the formula denote the omitted terms corresponding to the propagation of the ground wave, the induction field and the effect of ground in the second approximation [6 and 20].

The quantities I, l_∂, r_1, r_2, h_1 and h_2 in Eq. (7) can be calculated or measured. The effective length of the transmitting dipole is calculated from (4); the current I can be measured with an error of the order of 1-2% and the distance and heights with an error of less than 0.5% [6].

The unknown quantity in (7) is the reflection coefficient $\dot{R}$ which depends on the ground parameters whose values in turn change with meteorological conditions [7 and 21].

In certain cases it is possible to avoid measuring $\dot{R}$. In the antenna technique especially in the micro-wave range, field strength is often measured with the reflected ground wave eliminated. This is achieved by placing a metallic net which stops the reflected wave reaching the receiving antenna [22].

The diffraction of an electromagnetic wave from a metallic net can be calculated for a general case, the analysis of this condition, however, leads to very complicated formulas which are difficult to use for design purposes. With certain limitations of the net parameters and angles of incidence of the waves the formulas simplify and become suitable for design purposes. The calculations cited in [23] show that the values of the energy passed through and reflected from the net can be calculated with the required accuracy only under certain measuring conditions, which reduces the practical value of this method. Therefore in order to be able to measure the field strength with the maximum possible accuracy, methods are used in which the reflection coefficients can be accurately calculated.

The simplest method in this respect would appear to consist in using a "metallized ground," since in this case the modulus $|\dot{R}|$ of the reflection coefficient equals + 1 and the angle $\Theta = \pi$ with horizontal polarization and at any angle of elevation ψ [7]. However there are reasons which prevent the use of a metallized ground. The main reason being the increase in the error of measurement of the field strength as compared with a badly

conducting ground. Hence it is not advisable to use a metallized ground in the frequency range under consideration and measurements have to be made taking into consideration the real ground parameters.*

The ground parameters are determined by measuring the relative field strength with the electromagnetic wave striking the ground vertically [6]. Both dipoles, the transmitting and the receiving, are placed on the same supports and in the same plane perpendicular to ground. The transmitting dipole is above the receiving one and parallel to it. The height h_1 of the transmitting dipole is constant, the height h_2 of the receiving dipole is varied. Distance $r_1 = h_1 - h_2$ and distance $r_2 = h_1 + h_2$. The angle of elevation is $\psi = 90°$.

In this case (7) can be written as:

$$|\dot{E}| \simeq \frac{60\pi I l_d}{\lambda}\left|\frac{1}{h_1 - h_2} + \frac{\dot{R}e^{j4\pi h_2/\lambda}}{h_1 + h_2}\right|. \tag{18}$$

The approximate shape of the curve is shown in Fig. 2.

The reflection coefficient is determined after simple transformations from relative measurements:

$$|\dot{R}| = \frac{k\,/\,h_1 - h_{2\,\mathrm{min}} - 1\,/\,h_1 - h_{2\,\mathrm{max}}}{k\,/\,h_1 + h_{2\,\mathrm{min}} + 1\,/\,h_1 + h_{2\,\mathrm{max}}} \tag{9}$$

where $h_{2\mathrm{min}}$ and $h_{2\mathrm{max}}$ are the heights of the receiving dipole at points corresponding to $|\dot{E}|_{\mathrm{min}}$ and $|\dot{E}|_{\mathrm{max}}$ and $\underline{k}$ is the standing-wave factor $k = |\dot{E}|_{\mathrm{max}}/|\dot{E}|_{\mathrm{min}}$.

The relative ground permittivity is determined from the known equation for $\dot{R}$:

$$\dot{R} = \frac{\sin\psi - \sqrt{\epsilon'_k - \cos^2\psi}}{\sin\psi + \sqrt{\epsilon'_k - \cos^2\psi}} \tag{10}$$

where ψ is the angle of elevation; ϵ'_k is the relative complex permittivity of ground $\epsilon'_k = \epsilon' = j\,60\lambda\sigma$.

In the case of vertical angles of incidence ($\psi = 90°$) and frequencies above 50-75 Mc at which $\epsilon' \gg 60\lambda\sigma$ the permittivity of ground is:

$$\epsilon'_k = \left[\frac{1 + |\dot{R}|}{1 - |\dot{R}|}\right]^2. \tag{11}$$

The reflection coefficient at any angle of elevation is determined from (10) with a ϵ'_k obtained from (11), i.e., from the results of measurement in the vertical plane. The field strength in this case is:

$$|\dot{E}| \simeq \frac{60\pi I l_d}{\lambda}\left\{\left(\frac{1}{r_1} - \frac{|\dot{R}|}{r_2}\right)^2 + \frac{4|\dot{R}|}{r_1 r_2}\sin^2\left[\frac{\kappa(r_2 - r_1)}{2}\right]\right\}^{1/2}. \tag{12}$$

Variations in the ground parameters distribution around the antenna apparently affect but little the resulting error in the field strength measurements; this assumption however, requires experimental confirmation.

SUMMARY

In the 30 to 600 Mc range only those measurements can be considered reliable which have been obtained by comparing the results provided by the reference antenna and the reference field methods. Tuned half-wave dipoles raised above the ground should be used for measurements. When field strength is measured with an accuracy of 5-10% the antenna height above ground should not be less than 0.5λ.

The effect of various pick-ups is decreased by measuring at relatively high signal levels ranging from tens to hundreds of millivolts per meter. The direct component of the crystal rectifier or thermal detector voltage must be measured on a potentiometer.

*It would appear that the substitution of the ground surface by water (lake, sea) will not simplify measurements, since the conductivity of water also greatly depends on meteorological conditions [21] and the antenna height must be increased.

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THE RELATION OF THE "Q" FACTOR OF QUARTZ CRYSTAL LENSES TO THEIR GEOMETRICAL DIMENSIONS

E. D. Novgorodov and N. Kh. Neparidze

At present the highest Q factor of 10-12 millions has been attained in lens shaped quartz crystal resonators [1 to 5]. However, in the technical literature there are as yet no exhaustive data on the relation between the Q factor of lenses and their geometrical dimensions. The present article contains the results of investigations carried out at the Khar'kov State Institute of Measures and Measuring Instruments for the purpose of clarifying this problem.

The authors of this article have established that with other conditions being equal the Q factor of crystal lenses (Fig. 1) is determined by the relations between the geometrical dimensions and not simply by their values,

Fig. 1.

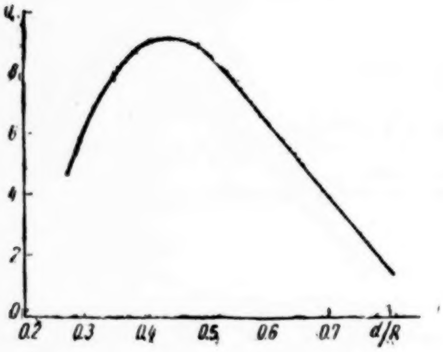

Fig. 2.

for instance by the ratio of the lens diameter d to the radius of curvature R. The size of the lens has a much smaller effect on its Q factor than the ratio d/R.

On the basis of experimental data a curve of the lens Q factor was plotted against the ratio d/R (Fig. 2). Above curve has been obtained for lenses of a frequency of some 500 kc. It has a maximum at d/R = 0.43.

Further investigations of lenses of other frequencies (about 100 and 1,000 kc) have shown that all lenses both large and small have about the same optimum ratio for d/R.

The value of the Q factor for large lenses (of a lower frequency) is higher than for smaller lenses. With considerable deviation of the d/R ratio from its optimum value, however, even large lenses have a smaller Q factor than smaller ones with a correctly chosen d/R ratio.

Thus the maximum Q factor in lenses is determined, within certain limits of size, by the relation between their dimensions and not by their size.

Above relation provides the possibility of calculating the optimum shape of lenses for any given frequency. In fact the frequency of a lens shaped quartz crystal resonator is determined from the formula [6]:

$$f = \frac{1.68 + 0.485\,\frac{d}{R}}{h}\ \text{Mc},$$

where h is the thickness of the lens, mm. Substituting the optimum value for d/R = 0.43 into this expression we find:

$$h = \frac{1.89}{f}\ \text{mm}, \qquad (1)$$

Writing the formula relation the various geometrical dimensions of the lens $R = d^2 + h^2/4h$ in the form $d/R = 4hd/d^2 + h^2$ and substituting the actual values for d/R and h we obtain:

$$d = \frac{17.4}{f}\ \text{mm} \qquad (2)$$

From the equality d/R = 0.43 we have:

$$R = \frac{40.5}{f}\ \text{mm} \qquad (3)$$

Formulas (1), (2) and (3) give the geometrical dimensions of a crystal lens at any given frequency for a maximum Q factor.

It will be seen from Fig. 2 that the maximum Q factor obtained for lenses at 500 kc is equal to 9 millions. This does not mean, of course, that this relation limits the Q factor to that value. Under more favorable conditions, for instance, with a better finish of the lens surface, a better holder and with a larger lens it is possible to obtain higher values of the Q factor, yet under the new conditions the former relationship between the parameters will be preserved, with the curve being shifted upwards and slightly changed in shape.

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SCREENED MEASURING COMPARTMENTS

S. A. Lintov and G. P. Gusev

According to the "specifications for the maximum permissible man-made radio interference" a screened compartment must reduce the level of the interfering field inside it to a maximum of 2 μv over the entire frequency range for which the compartment is designed, and must provide, for the sources of interference under test and measuring apparatus, supplies in which radio interference does not exceed 2 μv.

In order to meet these requirement the compartment must be correctly designed with suitable materials and appropriate filters chosen for suppressing radio interference in the incoming lighting and supply leads.

Design of Screened Compartments. From the point of view of effective screening, cost of material and simplicity of manufacture of a screened compartment, sheet steel has certain advantages. When a wire-netting screen is used, however, problems of ventilation and lighting of the compartment are simplified. Wire-netting compartments are therefore also widely used.

In order to decide finally on the material to be used it is necessary to have a tentative figure for the expected efficiency of screening, i.e., to know by what amount the interfering field has to be reduced.

With this object in view it is first advisable to measure the interfering field level in the place where the compartment is to be installed. These measurements should be made at different times of the day over the entire frequency range in question.

Assuming that the maximum level of the interference field inside the compartment must not exceed 2 μv, the required efficiency of the compartment can be determined as follows:

$$E_T = \frac{U_n}{2}, \quad \text{or} \quad E = 20 \ \lg \frac{U_n}{2} \ \text{db}, \tag{1}$$

where E is the efficiency of the screened compartment; U_n is the level of the interfering field outside the compartment, μv.

The efficiency of the screened compartment, depending on the use for which it is designed and the level of interference lies usually in the limits of 10^2 to 10^5, i.e., between 40 and 100 db. Compartments with a 40 db efficiency will provide freedom from interference due to remote industrial and medical high-frequency apparatus or radio transmitters. If such equipment or radio transmitters are near to the compartment it must have an efficiency of 100 db or even higher. Such an efficiency is provided by a compartment made of sheet steel 1 to 1.5 mm thick.

The efficiency of a continuous screen can be approximately calculated from the formula:

$$E = 1.5 E_m E_\partial = 1.5 \,\mathrm{ch}\,\alpha t + \left[1 + 0{,}5\left(\frac{z_\partial}{z_m} + \frac{z_m}{z_\partial}\right) \mathrm{th}\,\alpha t\right].^* \tag{2}$$

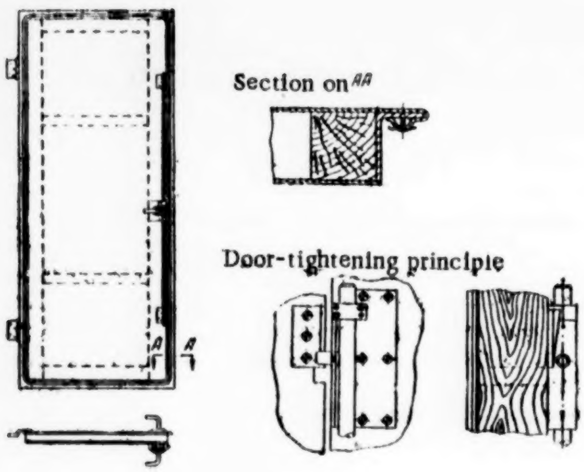

Fig. 1.

Here E_m is metals creening determined from the expression $E_m = \cosh \sigma t$; E_0 is screening by means of reflection represented by expression:

$$E_0 = \left[1 + 0.5\left(\frac{z_\partial}{z_m} + \frac{z_m}{z_\partial}\right) \operatorname{th} \sigma t\right],$$

where σ is the eddy currents factor, 1/mm; for steel it is for instance $\sigma = \sqrt{j} \cdot 75.6 \cdot 10^{-3} \sqrt{f}$; t is the screen thickness, mm; z_∂ is the impedance of the dielectric, ohms.

For air it is $z_\partial = 7.9 \cdot 10^{-9} f R_e$,

where $R_e = \sqrt[3]{\frac{3V}{4\pi}}$.

z_m is the impedance of the metal, ohms. For steel it is $z_m = 10.44 \cdot 10^{-9} \sqrt{f}$.

By making a simple calculation it is possible to show that the efficiency of a single layer screened compartment of 3 x 2 x 2 m made of a 1 mm thick steel sheet will be over 130 db at a frequency of 0.15 Mc.

In the overwhelming majority of cases under factory and even laboratory conditions compartments with an efficiency of 65 to 70 db provide the possibility of measuring radio interference. Such an efficiency is obtained in a single layer compartment made of copper wire netting with a mesh of 2.5 to 3 mm and a wire diameter of 0.4 to 0.5 mm.

A compartment made of a single tinned low-carbon steel wire netting with a mesh of 2.5 to 3 mm provides an efficiency of the order of 55-60 db and with a double screen (the outer an inner screens being spaced by 50 to 100 mm) about 90 db.

In calculating and designing wire-net screened measuring compartments the formula of M. I. Kontorovich is widely used:

$$E = 1 + \frac{2\pi R_e}{3S} \cdot \frac{1}{\left[\lg\frac{S}{r_0} - 1.5 + \frac{\mu}{\sqrt{2}\,\sigma r_0}(1 - j)\right]}, \tag{3}$$

where

$$\frac{\sigma R_0}{2\sqrt{2}} = \frac{R_\sim}{R_0},$$

R_0 is the dc resistance of wire; $R_\sim$ is the ac resistance of wire; μ is the permeability; S is the width of the mesh; r_0 is the wire radius; σ is the eddy current factor and R_e is the radius of an equivalent spherical screen.

For a rectangular screened compartment the value of R_e is found from the expression:

$$R_e = \sqrt{\frac{3V}{4\pi}}, \tag{4}$$

where V is the volume of the screened compartment and σ is the eddy current factor determined from expressions:

for copper $\sigma = 21{,}2 \cdot 10^{-3} \sqrt{f}$;

for steel $\sigma = 75{,}6 \cdot 10^{-3} \sqrt{f}$;

for aluminum $\sigma = 16{,}35 \cdot 10^{-3} \sqrt{f}$.

*Ch = cosh; th = tanh.

The efficiency of screening by means of a double wire-netting screen is determined from the expression:

$$E = E_1 E_2 \frac{1}{1-\left(1-\frac{1}{E_1}\right)\left(1-\frac{1}{E_2}\right)}, \quad (5)$$

where E_1 and E_2 are the efficiencies of screening of the internal and external screens calculated from (3).

It is possible to calculate that the efficiency of a single screened compartment of 3 x 2 x 2 m made of copper wire netting with a mesh of S = 3 mm and wire diameter of 0.5 mm will not be less than 64 db at a frequency of f = 0.15 Mc.

At higher frequencies the efficiency of screening will increase.

Construction of the Compartment. The size of the compartment is chosen on the basis of its intended use, cost and available space. Usually the compartments have an area of 6-8 m^2 and a height of 2.5-3 m, when, however, it is necessary to measure radio interference of large objects (for instance automobiles), large generating sets and other bulky electrical machinery, the compartment area may reach several dozen square meters.

The screening can be made of sheet metal or wire-netting drawn across a metal or wooden frame. The metal or wire-netting sheets must make a good electrical contact along their entire perimeter. Such a contact in the case of metal sheets can be ensured by electric welding or soldering. The seam must be continuous in order to ensure a one-piece, effective screening.

For wire-netting compartments any type of seam which provides good electrical contact between the sheets at a spacing of not less than every 10-15 mm is suitable. For this purpose either soldering or spot welding may be used.

The compartment doors must also be screened. When the door is closed a good electrical contact must be ensured between it and the walls of the compartment along its entire perimeter at a spacing of at least 10 to 15 mm. For this purpose it is possible to use a spring comb made of phosphor bronze fixed along the entire internal perimeter of the door frame and making good contact with the main screen when the door is closed by means of a clamping lock.

The construction of the door with the clamping lock which ensures a good electrical contact with the screened compartment is shown in Fig. 1.

If there are any windows in the compartment they should be screened by means of one or better still two layers of copper wire netting with a netting not exceeding 2 x 2 mm, and with a distance between the two screens of at least 50 mm. Both layers should have a good electrical contact with the walls of the compartment (the frame) along their entire perimeter. It is more convenient to make the nets dismountable. The metal framework of the window nets must also have spring contacts in the shape of a phosphor bronze comb.

The ventilation holes like the windows can be covered with wire netting. A thick netting, however, prevents a free flow of air impeding ventilation. From this point of view it is better to connect to the ventilation hole a branch pipe which is made to serve as a waveguide filter. The branch pipe must be welded or soldered to the compartment wall along the enter perimeter of the hole.

It is known that waveguides act as high pass filters with a cut-off frequency determined by the shape and size of the waveguide. For a square waveguide the critical wavelength λ_0 does not exceed double the width of the waveguide. In cylindrical waveguide, λ_0 is determined from relation $\lambda_0 = 1.71$ d, where d is the waveguide diameter.

It is obvious that the ventilation hole should be made of such a size as not to admit radio interference within the screening range of frequencies.

On the basis of the "Specifications for the maximum permissible man-made radio interference" (1956 issue) the highest frequency of the screened range is $f_0 = 400$ Mc ($\lambda_0 = 75$ cm). Hence under the above conditions the ventilation hole should have a radius of $r < \lambda_0/1.71$, i.e., smaller than 44 cm and in case of a rectangular hole the largest side should be $b < \lambda_0/2$. Moreover it should be remembered that there will be some penetration of interference radio-waves longer than λ_0.

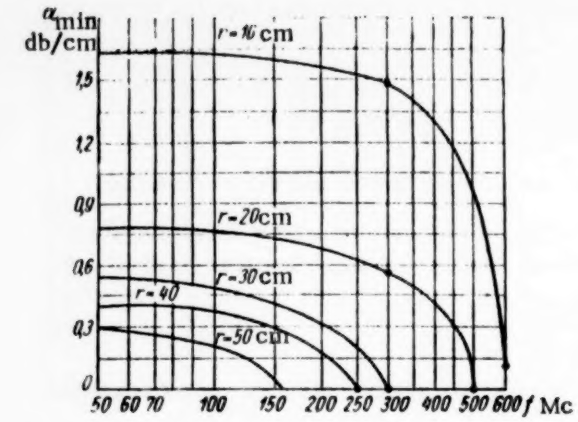

Fig. 2.

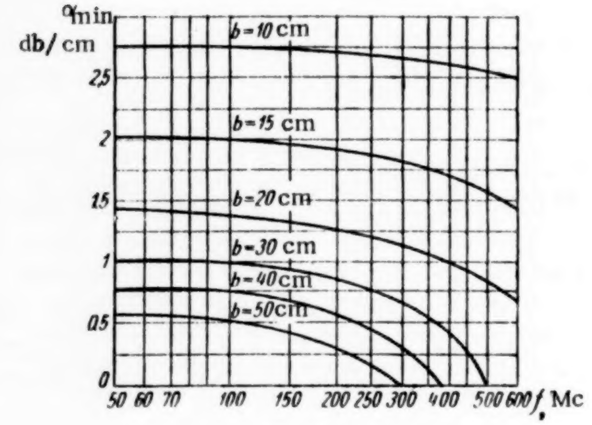

Fig. 3.

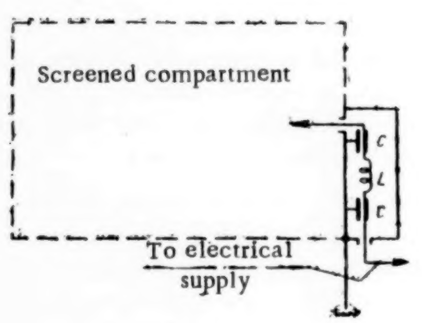

Fig. 4.

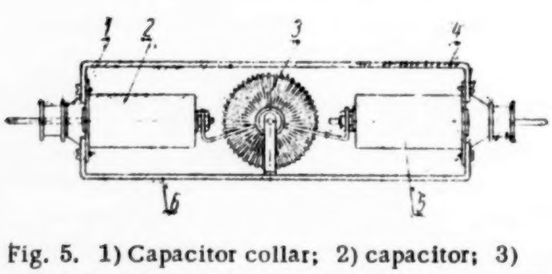

Fig. 5. 1) Capacitor collar; 2) capacitor; 3) toroidal coil; 4) filter lid; 5) capacitor; 6) filter body.

The metal branch tube will greatly increase the attenuation of the interfering field. The value of this attenuation α depends only on the dimensions of the pipe and not on the metal from which it is made.

Of all the existing types of waves the minimum attenuation α_{min} db per unit length of the waveguide is determined by the following relations: for a rectangular waveguide:

$$\alpha_{min} = \frac{27.3}{b}\sqrt{1-\left(\frac{2b}{\lambda}\right)^2}\,; \qquad (6)$$

for a cylindrical waveguide:

$$\alpha_{min} = \frac{16}{r}\sqrt{1-\left(\frac{3.41r}{\lambda}\right)^2}\,, \qquad (7)$$

where λ is the wavelength in free space, cm; b is the larger side of the rectangular cross section of the guide, cm and r is the radius of the waveguide.

Figures 2 and 3 show curves of α_{min} plotted against frequency for cylindrical and rectangular waveguides respectively for various values of r and b.

If provisions for heating or water supplies are made in the compartment, the central heating or water pipes must be carefully soldered or welded to the screen of the compartment at their entry and exit along the whole of their perimeter. This is necessary in order to prevent the penetration of interference along these pipes into the compartment.

For reasons of safety the compartment must be grounded and the grounding busbar securely connected to the screen at one point on the external surface near to the filter. The floor and walls of the compartment must be covered by an insulating material (for instance plywood).

In the case of a compartment with a double screen both screens are grounded at one point near the filter.

Filtering Supply Interference. In order to prevent the penetration of radio interference along the supply leads, all the conductors entering the screened compartment must pass through radio-frequency suppressing filters so that the level of interference in the leads to which the sources of interference under test and the measuring equipment are connected does not exceed 2 μv. Such a suppression of radio interference is obtained in practice in the overwhelming majority of cases by a filter which possesses over the whole frequency range at which measurements are made an efficiency of 10^5 (100 db).

The circuit and design of the filter is determined by the voltage and current in the filtered conductors. At currents not exceeding 50 amp the filter output inside the screened compartment must be terminated for each lead to which a set is connected by a coil of 400 μh, and with currents exceeding 50 amp by a coil of at least 2 μh.

Choke output filters are used in order to avoid any shunting effect of filter capacitors on the radio interference measurements of the tested sources of interference. One of the possible versions of the circuit and the construction of the filter for the range of 0.15 to 150 Mc is shown in Figs. 4 and 5. Feedthrough capacitors, which have a better high-frequency loss characteristic than other types, and coils wound on sendust cores type TCh or VCh should be used.

It should be noted, however, that in wide-band highly efficient filters it is often necessary to use capacitors with residual inductance in addition to feedthrough capacitors in order to provide higher attenuation in the lower frequency portion of the suppressed band.

The capacitors should be of the order of 0.5-1 μf. The value of the coil inductance is determined from the relation $L_{\mu h} \cdot C_{\mu f} = 10$ to 100. The filter must be mounted in a metal case with separate compartments for each section. The case should be closed with a tightly fitting lid. The input and output of the filter should be carefully separated at high frequencies, i.e., should be screened in order to avoid coupling between the output and the input of the filter.

The filter is fixed on the outside of the compartment at the point where the leads enter into it through branch tubes carefully soldered or welded along their entire perimeter to the filter case and the compartment screen. When the filter is fixed to a compartment screened with wire-netting it should be mounted on a tinned metallic plate, which should be soldered to the screen and fixed to the framework of the compartment.

ACOUSTICAL MEASUREMENTS

SYSTEMATIC ERROR IN REPRODUCING UNIT SOUND PRESSURE

A. N. Rivin

The method of reproducing a unit sound pressure in a resonating tube is based on the well-known relation between the maximum oscillatory velocity (V_0) and sound pressure (P_0) in the field of flat standing waves: $P_0 = WV_0$ (W is the impedance of the medium). In the initial application of the method developed by the VNIIM* [1] sound pressure on the microphone membrane which closed the end of the tube was measured by means of the angle of deflection of a Rayleigh disc placed in the middle of the tube, at the oscillatory velocity antinode.

In 1955 a similar installation was erected at the VNIIFTRI.** During testing considerable systematic errors were discovered whose reasons could be ascribed to factors which infringed the conditions for obtaining flat standing waves. Among these factors we shall examine the unevenness of the internal cross section of the tube and the attenuation of sound in the tube.

Effect of the uneven internal cross section of the tube. In the existing installations changes in the internal cross section of the tube can be caused by inserts at both ends of the tube which serve to tune it by altering its length in order to obtain an antinode of the oscillatory velocity at the place where the Rayleigh disc is fixed.

Since inserts of different profiles and dimensions may be used in the installation it is of interest to examine two extreme cases which correspond to a smooth decrease in the internal cross section by means of a conical insert and to a sudden decrease obtained with a cylindrical insert. Let us write the limiting conditions at the closed end for the two instances in the form

$$x = x_0 \quad P_1 = P_0; \; V_1 = 0$$

For a conical insert whose longitudinal cross section is shown in Fig. 1 the sound pressure and oscillatory velocity inside the insert ($x_0 \leq x \leq x_0 + l$) can be determined from the general expressions for an incident and reflected spherical wave [2]:

$$P_1(x) = P_0 \frac{x_0}{x}\left[\cos k(x-x_0) + \frac{1}{kx_0}\sin k(x-x_0)\right]$$

$$V_1(x) = \frac{P_0}{iWk^2x^2}\left[k(x-x_0)\cos k(x-x_0) - (k^2xx_0+1)\sin k(x-x_0)\right],$$

At the junction of the tube and the insert ($x = x_0 + l$) conditions $V_1 = V_2$ and $P_1 = P_2$ must hold. The equation of a standing wave in a tube with a constant cross-section ($x \geq x_0 + l$) has the form:

$$P_2(x) = \frac{x_0 P_0}{x_0 + l}\,\frac{\cos kl + \frac{1}{kx_0}\sin kl}{\cos(kl+\beta)}\cos[k(x-x_0)+\beta].$$

$$V_2(x) = \frac{P_0 x_0}{iW(x_0+l)}\,\frac{\cos kl + \frac{1}{kx_0}\sin kl}{\cos(kl+\beta)}\sin[k(x-x_0)+\beta].$$

where β is the additional phase shift which arises owing to the conical insert:

*VNIIM = All-Union Scientific Research Institute of Metrology.

**VNIIFTRI = All-Union Scientific Research Institute for Physico-Technical and Radiotechnical Measurements.

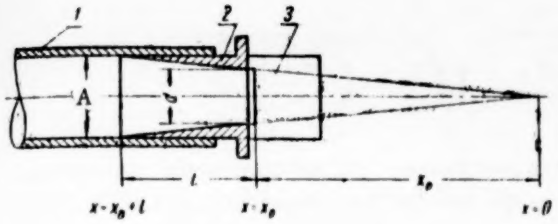

Fig. 1. Junction of a microphone to a tube by means of a conical insert. 1) Tube; 2) insert; 3) microphone

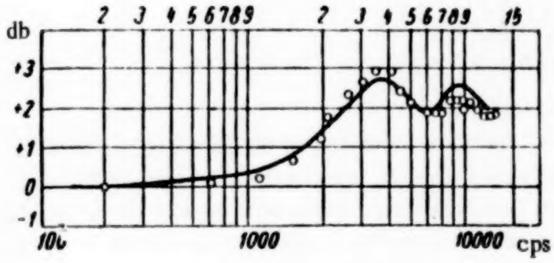

Fig. 2. The ratio of microphone sensitivity (in db) with and without a conical insert in a small tube; l = 30 mm, 1/a = 1.3.

$$\mathrm{tg}(kl+\beta) = \frac{1}{k(x_0+l)}\cdot\frac{[k^2x_0(x_0+l)+1]\,\mathrm{tg}\,kl-kl}{kx_0+\mathrm{tg}\,kl}.$$

If the distance (L) from the microphone membrane to the Rayleigh disc is chosen in such a manner that the disc is at an oscillatory velocity antinode and a sound pressure node [$kL + \beta = (2n-1)\pi/2$], the ratio of the sound pressure acting on the microphone membrane to the oscillatory velocity measured by the Rayleigh disc will be:

$$\left|\frac{P_0}{V_0}\right|_{\mathrm{res}} = W\left[\frac{a}{1+(a-1)\dfrac{\mathrm{tg}\,kl}{kl}}\cdot\frac{\cos(kl+\beta)}{\cos kl}\right],$$

where $\underline{a}$ is the ratio of the insert neck and tube diameters:

$$a=\frac{d}{D}=\frac{x_0}{x_0+l}$$

By neglecting the effect of the insert in calculating the level of sound pressure we make a systematic error of:

$$\delta_k = 20\ \lg\left[\frac{a}{1+(a-1)\dfrac{\mathrm{tg}\,kl}{kl}}\cdot\frac{\cos(kl+\beta)}{\cos kl}\right]\mathrm{db}.$$

In the case of the cylindrical insert we can write the limiting conditions at the junction of the insert with the tube ($x = l$) in the form $P_1 = P_2$ and $V_2 = V_1a^2$. Calculations similar to those carried out above will in this case lead to the following expression for the error in microphone calibration:

$$\delta_c = 20\ \lg\left[\sqrt{\frac{1+\mathrm{tg}^2kl}{1+a^4\,\mathrm{tg}^2\,kl}}\right]\mathrm{db}.$$

Figures 2 and 3 show the systematic errors of microphone calibration in the case of a conical insert of a length l = 30 mm and a cylindrical insert of a length l = 20 mm with a ratio of the tube and insert diameters of 1/a = 1.3.

The calculations were checked experimentally by repeated calibrations of a standard microphone with and without inserts. The measurement results as shown in Figs. 2 and 3 coincide with calculations within the limits of random errors of measurement equal to 0.2 db, which shows the possibility of applying these relationships for the calculation of the possible systematic error in reproducing unit sound pressure. By using these relationships it is possible to show that for a tube with an internal diameter of 15 mm even with a smallest practically possible insert the systematic errors will exceed the permissible value of 0.2 db. Thus if the length of the insert is about one quarter of a sound wavelength, the thickness of the insert walls must not exceed 0.075 mm for a systematic error not exceeding the permissible value of 0.2 db; and if the ratio of the diameters is 1/a = 1.3, the length of the insert must not exceed 1.5 mm.

Thus the required accuracy of reproducing unit sound pressure can only be attained in practice without any inserts which change the internal cross section of the tube.

Effect of the attenuation of sound waves in the tube. With losses either distributed along the tube or concentrated at its end the ratio of the sound pressure at the end of the tube (P_0) to the oscillatory velocity measured by the Rayleigh disc (V_0) is equal to [2]:

$$\left|\frac{P_0}{V_0}\right| = W \frac{\mathrm{ch}\,\psi_0}{\sqrt{\mathrm{ch}^2\left(\psi_0+\frac{\varkappa L}{c}\right)-\cos^2\frac{\omega}{c}L}} \cdot \frac{1}{\sqrt{1+\left(\frac{\varkappa}{\omega}\right)^2}} .$$

where L is the distance from the Rayleigh disc in the microphone membrane; χ is the attenuation constant and ψ_0 is determined by the relative acoustic resistance at the end of the tube (Θ) from expression tanh $\psi_0 = \Theta$.

At odd resonance when the length L contains an odd number of quarter wavelengths $kL = (2n-1)\frac{\pi}{2}$,

$$\left|\frac{P_0}{V_0}\right|_{res} = W \frac{\mathrm{ch}\,\psi_0}{\mathrm{ch}\left(\psi_0+\frac{\varkappa}{c}L\right)} \frac{1}{\sqrt{1+\left(\frac{\varkappa}{\omega}\right)^2}}$$

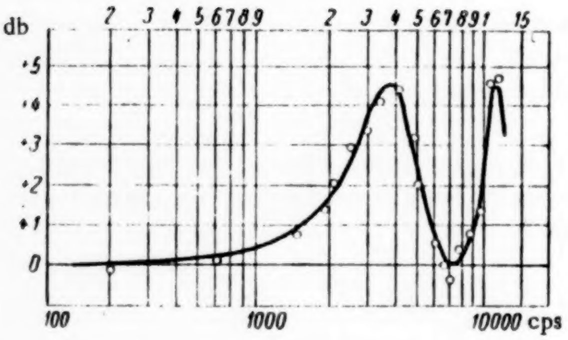

Fig. 3. The ratio of microphone sensitivity (in db) with and without a cylindrical insert; l = 20 mm, 1/a = 1.3.

If the attenuation of the sound in the tube be neglected when P_0 is calculated a systematic error will be made whose value will depend on χ and ψ_0. It should be noted that losses concentrated at one end of the tube only, ($\chi = 0, \psi_0 \neq 0$) for instance, when calibrating an acoustic probe which has a purely resistive acoustical impedance, cannot lead to systematic errors. Without concentrated losses at one end of the tube ($\psi_0 = 0$) and small attenuation of sound in the tube ($\chi \ll \omega$) the systematic relative error of reproducing a unit sound pressure is equal to:

$$\delta_n \simeq \frac{1}{2}\,\mathrm{sh}\,\frac{\varkappa}{c}L \cdot 100\%.$$

Quantity δ_n can be determined experimentally at datum points corresponding to odd resonance by using the ratio between the sound pressure P_0 at the closed end of the tube and that in the middle of the tube (at the pressure node) P_L:

$$\left|\frac{P_L}{P_0}\right| = \sqrt{\mathrm{sh}^2\frac{\varkappa}{c}L + \sin^2\left[\frac{\pi\Delta\omega}{2\omega_n}(2n-1)\right]} .$$

If a constant pressure in the middle of the tube is maintained with the help of an acoustic probe and the double relative detuning ($1/Q_n$), corresponding to an acoustic pressure at the end of tube($\sqrt{2}$ of the pressure at resonance) is measured, it is possible to determine the systematic error δ_n by means of the equality:

$$\mathrm{sh}\frac{\varkappa}{c}L = \sin\left[\frac{\pi}{4Q_n}(2n-1)\right] \qquad \delta_n \simeq \frac{\pi^2(2n-1)^2}{0.32\,Q_n^2}\%.$$

Results of measurements carried out in this manner showed that the errors due to attenuation of sound in the tube rise with frequency. For a large tube (of a 50 mm diameter) they can reach 1%; for a small tube (of a 15 mm diameter) at frequencies of 8-12 kc they may rise to 3% which exceeds the permissible error in reproducing unit sound pressure.

In order to eliminate these errors it is possible to utilize the errors arising through off-resonant tuning since the latter have the opposite sign to the former and with a suitable choice of mistuning the two errors can cancel each other.

Near to resonance when

$$kl = (2n-1)\,\frac{\pi}{2}\left(1 \pm \frac{\Delta\omega}{\omega_n}\right),$$

the ratio of P_0/V_0 can be written as follows:

$$\left|\frac{P_0}{V_0}\right| = W\,\frac{1}{\sqrt{1+\sin^2\left[\frac{\pi\Delta\omega_{ms}}{2\omega_n}(2n-1)\right]-\sin^2\left[\frac{\pi\Delta\omega}{2\omega_n}(2n-1)\right]}}.$$

The errors are compensated when $\omega = \omega_{ms}$ which corresponds to a decrease in sound pressure and oscillatory velocity by a factor of $\sqrt{2}$ with respect to their values at accurate tuning to resonance.

Thus in order to eliminate errors due to the attenuation of sound in the tube the microphone should be calibrated in a slightly detuned condition corresponding to a decrease in the angle of rotation of the Rayleigh disc to half its full value.

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ULTRASONIC THERMOELECTRIC RECEIVERS

L. K. Zarembo

The principle of operation of thermoelectric converters in ultrasonic measurements [1, 2] consists in converting the acoustic energy into heat with a subsequent measurement of it by a thermocouple. Thermoelectric receivers measure acoustic streams (intensity). The minimum intensities measured by thermal methods including thermoelectric ones are considerably higher than those measured by piezoelectric or mechanical methods. This is due to the difficulty of measuring small variations in temperature. The use of certain additional devices provides an extention of the thermoelectric receivers' range towards lower measuring limits. With these additions receivers can be used successfully, approximately from tenths of a watt per cm^2 upwards.

Thermoelectric receivers were used for measurements in liquids at frequencies ranging from several hundred kc to several Mc. It would appear that they could also be used at lower frequencies, however in that case, in order to obtain a satisfactory sensitivity a sufficiently efficient absorber should be used.

The characteristic relation between the thermocouple galvanometer deflection and the time of ultrasonic reception, which we shall call in future the thermal characteristic of the receiver, is shown in Fig. 1. The initial portion of the curve is linear followed by downward curving and finally a period of "thermal saturation," i.e., a condition in which the heat received in the absorber is balanced by the heat dissipated through conduction.* The form of this relationship is suggested by two possible conditions of work of a thermoelectric receiver: 1) a keying condition, i.e., working with a short exposure on the linear part of the thermal characteristic, the exposure being

*"Thermal saturation" is a rather inaccurate term, since the bend in the thermal characteristic can also depend on a number of ultrasonic wave processes whose development would require a certain time.

Fig. 1.

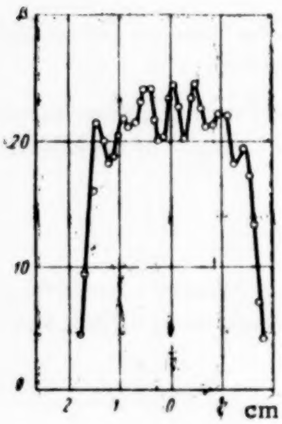

Fig. 2.

determined for the maximum ultrasonic intensity with which it will be required to operate; 2) a continuous condition which will produce thermal saturation. In both instances the galvanometer deflection must be proportional to the intensity.

Design of thermoelectric receivers. In measuring the absorption of ultrasonic waves of a finite amplitude in liquids [3] and in investigating the irregularities of the near field of a flat quartz crystal plate we used various types of thermoelectric receivers with copper-constantan thermocouples.* In the single-element thermoelectric receiver the working junction (usually soldered with tin) of the copper and constantan wire of 0.15 mm diameter was taken out of the thin drawn-out end of a glass tube and was covered with a rubber or a diacetate adhesive (a solution of diacetate cellulose in acetone). All further data refers to thermoelectric receivers with diacetate absorbers. The latter have better acoustic properties than the rubber ones and in addition are stronger mechanically. The nonoperative soldered joint of the receiver was placed in air inside the glass tube. The size of the sensitive head differed for different models (0.5 to 1 mm). The receiver is ready for use as soon as a thermal balance between the liquid and the air in the tube is established.

These thermal receivers were used for investigating the distribution of intensity in a nonhomogeneous near field. As an example of its application Fig. 2 shows measurements made with such a receiver and galvanometer M91a of the distribution of intensity (in conventional units) at a distance of about 2 mm from a flat quartz crystal plate 5 cm in diameter and silver electrodes 3.67 cm in diameter working at a fundamental frequency of 1.5 Mc.

In a nonhomogeneous near field (the Fresnel zone) it is necessary to have a distributed receiver in order to determine the ultrasonic intensity. Figure 3 shows a "distributed" thermal receiver: 25 copper-constantan thermocouples connected in series are distributed over a rubber backing in an ebonite capsule 4.5 cm in diameter. Other similar models with diacetate absorbers have up to 60 thermocouples. The placing of junctions under a thin absorbent layer leads to their better lagging and hence to an increase in the linear part of the thermal characteristic. The nonoperative junctions of the multielement receiver are taken out on the reverse side of the capsule and remain in the liquid. The multielement receivers, in addition to more even reception over the cross section of the beam, have a considerably greater sensitivity than single element receivers.

In both the single and multielement receivers the nonoperative and sensing junctions were placed as closely to each other as possible yet making the thermal effect of the sensing junctions on the nonoperative ones as small as possible. The heating of the medium by ultrasonic waves as well as random, sufficiently slow variations of temperature of the medium during testing by the keying method do not produce substantials errors, since each succeeding measurement begins at equal temperatures of the two junctions (with a zero indication on the galvanometer or microammeter).

Better lagging can be achieved by thermal insulation inside the capsules (for instance flaked felt, wadding etc). In the actual receivers used this was not necessary since the linear part of their characteristic was sufficiently large.

With exposures of 0.5-20 sec. and intensities from tenths of a watt per cm^2 to ~ 10 w/cm^2 at frequencies of 1.5-4.5 Mc these thermal receivers were used with galvanometer M91a or microammeter M91.

An ultrasonic wave of a finite amplitude is converted during propagation from a single into a multi-frequency wave [4] it is therefore necessary to know the thermal receiver sensitivity at various frequencies. Figure 4

*A copper-constantan thermocouple has a fairly large thermal emf ($41 \cdot 10^{-6}$ v/degree) it is stable and has a linear characteristic in the temperature range of 0-100°C.

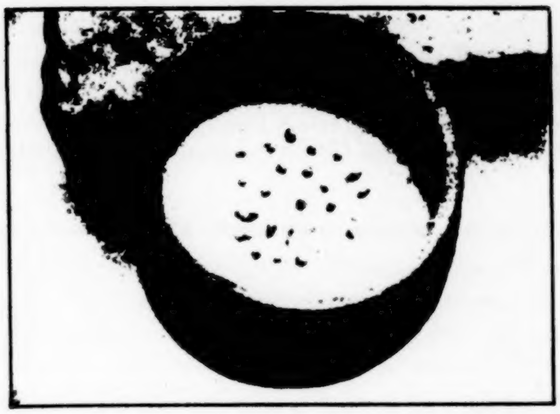

Fig. 3.

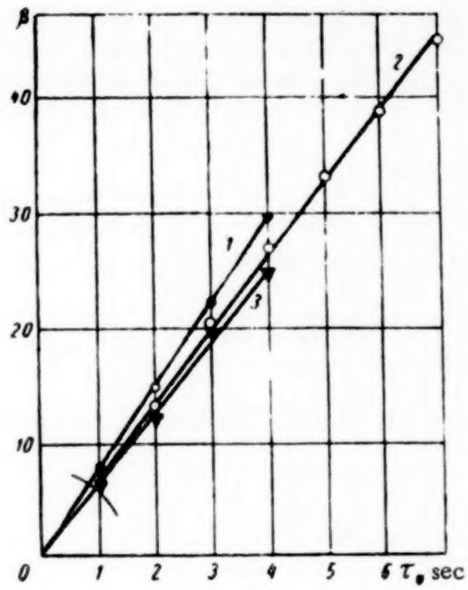

Fig. 4.

shows the thermal characteristics of a thermal receiver with 61 junctions and a diacetate absorber ~1 mm thick, and the characteristic determined in water at frequencies of ν = 4.5 (1); 2.84 (2) and 1.5 (3) Mc. These measurements were made with a radiator of 1.93 cm in diameter at a distance of 4 cm, and an even intensity of $j = 4.4$ w/cm². The intensity was determined both by the heating of water in a miniature heat insulated vessel and by means of a radiometer. The sensitivity of the receiver determined as $\gamma_{\nu} = 1/J_0\,(\Delta I/\Delta\iota)$, where I as the current flowing in the galvanometer at the respective frequencies was found to equal $\gamma_{4.5} = 2.5\cdot 10^{-8}$, $\gamma_{2.84} = 2.3\cdot 10^{-8}$ and $\gamma_{1.5} = 2.2\cdot 10^{-8}$ amp·cm²/w·sec. Thus in this frequency range at an intensity of 4.4 w/cm² the sensitivity does not vary by more than 15%. Measurements at lower sensitivities (down to sensitivities of the order of several hundredths of a watt per 1 cm²) have shown that the sensitivity at 4.5 Mc exceeds that at 1.5 Mc by no more than 20-25%.

It was also of interest to determine the effects of the heat and temperature of the medium. At equal intensities the heat conductivity coefficient in water is $k_{H_2O} = 601\cdot 10^{-5}$ w/cm·degree and in transformer oil $k_{oil} = 150\cdot 10^{-5}$; the ratio of the coefficients of temperature conductivity is $\lambda_{H_2O}/\lambda_{oil} = 1.8$. The comparison of thermal characteristics shows that the sensitivity of a thermal receiver is approximately twice as great in oil as it is in water. This it would appear is explained by heat conduction during the deflection of the galvanometer which is several times longer that the ultrasonic action on the absorber.

In addition to using multielement receivers other methods of increasing sensitivity are also possible: the use of a dc amplifier or an ac amplifier with a chopper. The application of the latter method is made difficult by the small thermal current.

The theory of the thermo-electric receiver. In order to determine the amount of heat liberated in the absorber it is convenient to introduce the concept of the integral effective thermal diameter of the absorber:

$\Sigma = \int_{v_0} \frac{Q}{qJ}\,dv$; here the integration is carried out over the whole of the absorber volume v_0, q is the mechanical equivalent of heat, J is the intensity of sound and Q is the amount of heat liberated in a unit volume of the absorber in unit time. Futher we shall also use a differential diameter: $\sigma = d\Sigma/dv = Q/qJ$. For an accurate determination of the effective diameter in general the problem of sound wave diffraction on the absorbing head must be solved and the distribution of heat in the absorber determined. In addition viscous losses near the surface of the absorber must be considered. In certain simple cases the effective diameter can be easily found. For instance in the case of a plane-parallel absorbing layer of thickness d when the edge effects are ignored with normal wave incidence and equal intensity along the wave front. $\Sigma = 2\alpha S d$, where 2α is the energy coefficient of absorption in the layer, S is the area of the layer or the area of the ultrasonic beam (whichever is the smaller). The differential diameter in this instance is $\sigma = 2\alpha$.

The effective diameter of a spherical absorbing head can also be determined approximately. Let a flat wave fall on a spherical head whose center is in $x = 0$. Without taking into consideration the diffraction effects

and reflection from the head surface we have:

$$\Sigma=2\alpha\int_{v_0} e^{-2\alpha(x+R)}\,dx\,ds=2\alpha\int_{-R}^{R} e^{-2\alpha(x+R)}\,(R^2-x^2)dx=\frac{\pi R}{\alpha}\left(1+e^{-4\alpha R}\right)-\frac{\pi}{2\alpha^2}\left(1-e^{-4\alpha R}\right).$$

For $4\alpha R < 1$, developing the exponents into series we obtain $\Sigma = (4\pi R^3/3)\,2\alpha = 2\alpha v_0$; v_0 is the volume of the head.

The thermal conductivity equation when the heating up of the receiver by ultrasonic effects is taken into consideration takes the form:

$$c\rho\frac{\partial T}{\partial t}=k\Delta T+qJ\sigma, \tag{1}$$

where $\underline{c}$ is the specific heat of the medium; ρ is the density of the medium and $\underline{k}$ is its thermal conductivity coefficient.

Let us examine a spherical absorbing head. If the dimensions of the absorber are considerably smaller than the wavelength it is possible to consider that $\sigma = \sigma$ (r). Let us find a stationary, spherically symmetrical solution of (1) which would satisfy the following conditions: T is finite at $r \to 0$ (r = 0 is location of the receiver head), $T \to T_0$ the initial temperature of the medium at $r \to \infty$. This solution can be found with an arbitrary differential diameter σ (r). In fact (1) has for this instance the form:

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dT}{dr}\right)=-\frac{qJ\sigma(r)}{k}.$$

Using double integration and considering the conditions at infinity we obtain:

$$T-T_0=\left(r^2\frac{dT}{dr}\right)_0\int_\infty^r\frac{dr}{r^2}-\frac{q}{k}\int_\infty^r\frac{1}{t^2}\left[\int_0^t s^2J\sigma(s)\,ds\right]dt.$$

Considering that the intensity does not depend on $rJ = J_0$ at $r \to 0$, we obtain the heating of the thermal receiver head:

$$\Delta T=-\left(r\frac{dT}{dr}\right)_{r\to 0}-\frac{qJ_0}{k}\int_\infty^0\frac{1}{t^2}\int_0^t s^2\sigma(s)\,ds\,dt. \tag{2}$$

If $\lim_{r\to 0}\left(r\frac{dT}{dr}\right)<\infty$ and $\int_\infty^0\frac{1}{t^2}\int_0^t s^2\sigma(s)\,ds\,dt<\infty$,

(2) will satisfy the above mentioned conditions. On the other hand if $\int_\infty^0\frac{1}{t^2}\int_0^t s^2\sigma(s)\,ds\,dt$ is not equal to zero, the reading of the thermoelectric receiver is a linear function of intensity, i.e., the receiver can be used under continuous operating conditions.

In a particular case by representing σ (r) in the form

$$\sigma(r)=\begin{cases}\sigma_0 & r<r_0\\ 0 & r>r_0\end{cases}.$$

we obtain $\int_\infty^0\frac{1}{t^2}\int_0^t s^2\sigma(s)\,ds\,dt=-\sigma_0 r_0^2/6$ and since in this case $\left(r\frac{dT}{dr}\right)_{r\to 0}=0$, $\Delta T=qJ_0\sigma_0 r_0^2/6k$. Hence with such a differential diameter δ (r) it is possible to operate under continuous reception conditions since $\Delta T \sim I_0$. It should be noted that the solution depends not only on the parameters of the receiver and the wave but also on the thermal conductivity of the medium.

In another particular case σ (r) $= \sigma_0\ \delta$ (r) there does not exist a spherically symmetrical stationary solution which would satisfy the afore-mentioned conditions.

Thus the possibility of working under continuous conditions with thermoelectric receivers is determined to a considerable extent by the geometrical characteristics of the receiving head. It should be noted that the readings of the galvanometer used with a multielement receiver under continuous operating conditions were not proportional to the intensity and it was only possible to use this receiver under keying conditions of operation, which provided readings proportional to the intensity.

SUMMARY

The thermoelectric ultrasonic receivers used for measuring medium and large intensities have certain advantages as compared with other types of receivers. These advantages comprise the following: 1) the nonresonating character of the thermal receivers (the difference in sensitivity at various frequencies can be partly eliminated by using efficient absorbents, which include in the range of 1.5-4.5 Mc diacetate cellulose films); 2) considerable inertia which leads to an averaging of the intensity fluctuations due both to cavitation and turbulence of the acoustic flow; 3) the thermal receivers measure intensity, a quantity which in the majority of cases is of the greatest interest.

Among the disadvantages of the thermal receivers should be cited: 1) a big time interval between measurements since receivers with good lagging have a large "thermal relaxation time" which lowers considerably the speed of measurement; 2) operating conditions for keyed working in liquids with different temperature conductivity coefficients must be fixed for each liquid separately.

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MEASUREMENTS OF LIQUID AND GAS FLOW

THEORETICAL BASIS OF CALCULATIONS FOR VOLUMETRIC-TYPE FLOW METERS FOR FLUIDS

I. A. Dmitriev

The fundamental work in the field of the theory of volumetric-type flowmeters is A. I. Petrov's thesis [1].

A. I. Petrov obtained the relation between the percentage error δ of the flowmeter, and the rate of flow and the leakage in the form where

$$\frac{\delta}{100}=\left(\frac{A}{Wt}-1\right)-\frac{Aq}{QWt}, \tag{1}$$

where A is the volume of liquid metered in one revolution of the meter pointer; W is the volume of the flowmeter chamber, equal to the theoretical volume of the liquid displaced by the flowmeter in one revolution or one oscillation; $\underline{t}$ is the ratio number, i.e., the number of revolutions or oscillations of the metering part when the meter is recording a volume equal to A; Q is the rate of flow of liquid through the flowmeter per unit time; $\underline{q}$ is the volume of liquid flowing per unit time through the clearance between the metering part and the walls of the measuring chamber, the volume being denoted as leakage.

The dependence of the percentage error on the amount of liquid flowing is expressed by an empirical formula;

$$\delta=C_1+C_2'\left(k''Q^{0.75}+\frac{k_0^{*}}{Q}\right)=C_1+C_2\left(Q^{0.75}+\frac{\lambda}{Q}\right), \tag{2}$$

where: k_1^{*}, k_0^{*}, C_1, C'_2 and C_2 are constants for a given meter determined experimentally when the flow of liquids with the constant μ and $\lambda = k_0^{*}/k^{*}$ is measured.

The dependence of the values k^{*}, k^{*}_0, C_2 and λ on the viscosity of the liquid is given in the form:

$$\frac{k''(\mu_1)}{k''(\mu_2)}=\sqrt{\frac{\mu_1}{\mu_2}},\quad \frac{C_2'(\mu_1)}{C_2(\mu_2)}=\sqrt{\frac{\mu_2}{\mu_1}},\quad \frac{k_0(\mu_1)}{k_0^{*}(\mu_2)}=\sqrt[8]{\left(\frac{\mu_2}{\mu_1}\right)^3}\quad \frac{\lambda(\mu_1)}{\lambda(\mu_2)}=\sqrt[8]{\left(\frac{\mu_2}{\mu_1}\right)^3}. \tag{3}$$

Expression (2) constitutes only a general representation of the dependence of the flowmeter error on the rate of flow, but gives neither the quantative dependence of δ on Q, nor the type, design features or geometrical dimensions of the meter, since the physical interpretation of k^{*}, k_0^{*} and C_2 values remains unexplained.

Expressions (3) gives the dependence of the above quantities on μ only, but the effect of liquid density ρ on δ and on the operation of the flowmeter is not taken into account.

In this connection (2) and (3) have no practical significance and can be used neither for calculations nor for the solution of the basic problems which are met with in the design, manufacture and operation of liquid flowmeters.

Reports in other foreign and home publications have been either partly discussed in [1] or they are of a general character and cannot be used for the solution of problems met with in the theory nor in the calculations in connection with flowmeters.

The object of the present work was to carry out a theoretical and experimental investigation of liquid flowmeters and to provide a theoretical basis for the choice of a design and evaluation of geometrical dimensions of the metering parts of a liquid flowmeter in a closed stream with a predetermined experimental error and for given practical operating conditions.

The following principles have been adopted in the development of the methods of investigation.

It is seen from (1) that the percentage error of a flowmeter depends not so much on the value $\underline{q}$, as on its relationship with Q. If there is a linear relationship between $\underline{q}$ and Q, the flowmeter error can be reduced to zero by means of varying W or $\underline{t}$ during the calibration of the meter.

To explain the nature of the dependence of $\underline{q}$ on Q let us determine the velocity of liquid in the clearance; for this purpose we shall make use of the Navier-Stokes differential equation for viscous incompressible liquid, in the same way as it was done in [1] and [2]. Since, under all operating conditions of the flowmeter, the flow of the liquid through the clearance is one-dimensional and laminar, the equations quoted earlier can be simplified considerably. After integrating these equations for given boundary conditions and for the layout of the coordinates shown in Fig. 1, we obtain an expression for determining the velocity of the liquid in the clearance:

$$V=\frac{1}{2\mu}\left(\frac{\partial p}{\partial x}+g\rho\right)\left[x^2-\left(\frac{h}{2}\right)^2\right]\pm\frac{U}{2}\left(\frac{x}{h/2}-1\right).$$

By integrating the expression over the cross section of the clearance we determine $\underline{q}$:

$$q=\pm\frac{hbU}{2}+\frac{bh^3}{12\mu}\left(\frac{p}{l}+g\rho\right)=\pm q_u+q_p\pm\frac{bh^3}{12\mu}g\rho$$

where $\underline{b}$ is the clearance length; $\underline{h}$ is the clearance; l is the depth of the clearance; U is the speed of the displacement of the moving surface in the clearance; $\underline{g}$ is the gravity constant; ρ is the density of the liquid; $q_u = bhU_p/2$ is the part of the leakage taking place as the result of the effect on the liquid of the moving surface in the clearance; $q_p = bh^3p/12\mu l$ is the part of the leakage taking place under the effect of the pressure drop of the liquid in the clearance; $(bh^3/12\mu)\,g\rho$ determines the effect of the weight of the liquid on the leakage. This factor can be positive or negative, depending on the direction of the flow of the liquid in the clearance.

When the working part of the meter is in motion, the position of the orifice and the direction of the motion of the liquid in the orifice change periodically in space, and hence the sign in front of the term containing $g\rho$ can change from plus to minus and vice versa. Let us assume arbitrarily that the term containing $g\rho$ cancels out when changing periodically its sign in the course of one revolution or one cycle of the working part,and hence it can be omitted in our calculations.

Without any significant effect on the accuracy of the calculations, the value U can be assumed to be proportional to Q. Therefore, the value q_c is a linear function of Q, and its effect on the flowmeter error can be counterbalanced by an appropriate change in W or $\underline{t}$.

The pressure difference, $\underline{p}$, between the liquid in front and behind the moving part of the meter (pressure drop across the clearance) which pressure difference causes the leakage of the liquid through the clearance actuates the moving part of the meter and determines the power equal to $N_{eng} = Qp$ and developed by the meter representing a hydraulic engine.

The power N_{eng} is only utilized to overcome the resistance to the motion of the moving part and, therefore,

$$N_{eng} = N_{res}, \text{ and } p = \frac{N_{eng}}{Q} = \frac{N_{res}}{Q}$$

As already indicated, that part of the leakage which is not counterbalanced by W or $\underline{t}$ is of special interest. Therefore, it is desirable to express the value $\underline{p}$ in the form of the sum of two components of which the first one, p_u, represents the pressure drop of the liquid across the clearance caused by the resistance whose magnitude depends on Q^2 and μ, and the second, p_Q, represents the pressure drop due to the remaining resistances. Consequently,

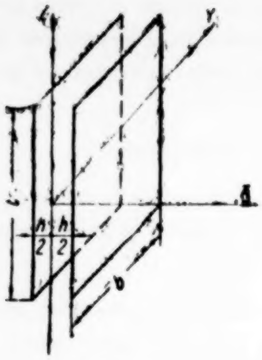

Fig. 1.

$$p = p_u + p_Q = \frac{N_u}{Q} + \frac{N_Q}{Q}.$$

Thus (1) can be expressed in the form

$$\delta = \delta_0 - \frac{bh^3 A \cdot 100\, N_Q}{12\, l\, Wt \mu Q^2},$$

where

$$\delta_0 = \left[\left(\frac{A}{Wt} - 1\right) + \frac{q_u}{Wt\,Q} - \frac{bh^3 A N_u}{12\, l\, Wt \mu Q^2}\right] 100.$$

A study of a liquid flowmeter should consist of an investigation of the operation of the flowmeter mechanism as a hydraulic engine and of an investigation of the nature of the relationship between the resistances, which have to be overcome by the meter, and the flow rate and the parameters of the liquid. With this object in view, we carried out a theoretical study of all the resistances which are to be overcome by the moving part of the flowmeter containing oval working wheels and a disc piston. The object of the study was to determine the dependence of individual resistances on the flow rate, the geometric dimensions of the meter and the parameters of the liquid measured; for the evaluation of the absolute value of individual resistances numerical coefficients were introduced. Such a method made the solution of the problem much easier and made it possible to generalize the results obtained for all types of volume flowmeters for liquids.

To obtain generalized results, it was found expedient to express all the geometrical dimensions of the main working parts of the liquid flowmeter in terms of one characteristic dimension; the nominal diameter, usually called "the size of the flowmeter", of a given flow area was taken as the characteristic dimension.

The type of the flowmeter should be taken to mean a family of meters, mechanically and hydraulically similar, which have the same ratio of the main dimensions of the working parts.

The total resistance to the motion of the working part of any type of flowmeter consists of three main components; the hydraulic resistance, the mechanical friction of the working part against the stationary supports, and the internal loads on the moving part of the meter.

Hydraulic Resistances. These are caused by the frictional forces between the surfaces of the working part and the liquid, and their magnitude depends on the type of liquid stream flowing over the frictional surface. The separate elements of the surface of the working parts of the meter, which interact with the liquid, can be divided into two groups according to the character of the flowing stream.

The first group consists of separate elements of the surface over which the laminar flow takes place. The surfaces which form clearances between the working parts and the walls of the measuring chamber belong to this group.

The friction force on the surfaces in the laminar flow depends on the liquid viscosity, μ, and the relative velocity of the liquid with respect to the friction surface. The frictional power of the surfaces of the working part over which the laminar flow of the liquid takes place can be expressed in the form

$$N_2' = \Theta_A \frac{\mu Q^2}{h D_v^2}.$$

where Θ_A is a numerical coefficient.

The second group consists of separate elements of the surface over which the turbulant flow of liquid takes place. The magnitude of the forces of the liquid friction against those surfaces depends on the flow conditions of the liquid in the boundary layer of the surface and can be expressed in the form

$$T = C_f \frac{U^2}{2} \rho F, \tag{4}$$

where C_f is resistance coefficient; U is velocity of the liquid; F is friction area.

The value C_f depends on the Reynolds number, Re, calculated for the length of the wetted surface as well as on the roughness of the frictional surface, and can be expressed in the form

$$C_f = \frac{\beta'}{\mathrm{Re}^{1-m}},$$

where β' is a numerical coefficient.

The power index m depends on the flow regime of the liquid in the boundary layer of the wetted surface. For the laminar flow of the liquid in the boundary layer $m_1 = 0.5$; and, in the turbulent flow, $m_2 = 0.8$. For very large Re, corresponding to the so-called "quadratic zone," $m_3 = 1$.

The total frictional force is the sum of the separate components, each of which is determined by (4), but with a coefficient C_f which has various power indices and, correspondingly, different numerical coefficients β.

An experimental check showed that the total frictional power can be expressed in a generalized form:

$$N_2^{\bullet} = \frac{\beta\mu^{1-m}\rho^m Q^{2+m}}{D_y^{3+m}}.$$

The general power index m for various meter types varies within very small limits and can be assumed to be equal to 0.8 on the average for all meters. The coefficient β is different for each type of meter and has to be determined experimentally.

In this way, the friction power of the surfaces wetted by a turbulent current can be determined by the equation

$$N_2^{\bullet} = \frac{\beta\mu^{0.2}\rho^{0.8} Q^{3.8}}{D_y^{3.8}}.$$

Mechanical Resistances. The supports of the working part are under a load which depends on the geometrical dimensions of the working part and on the pressure difference p. If we assume that the coefficient of friction of the bearings of the working part of the meter does not depend on the flow rate of a given liquid and remains constant, then the power required to overcome the mechanical resistances will constitute a certain part of the total power developed and can be expressed by

$$N_{mech} = \psi_A N_{eng} = \psi_A Q p$$

where ψ_A is numerical coefficient, depending on the friction coefficient which, in turn, depends on the lubricating properties of the liquid.

Internal loads. The internal loads consist of the resistances, which have to be overcome by the meter, of the driving gear between the shaft and pointers and other indicating parts and mechanisms. Let us assume that the moment of the internal resistances, M_i, is independent of the shaft speed and of Q.

The working parts of the meter may have to overcome additional resistances to the motion due to mechanical friction at an extreme reduction of the clearances, at bends, etc. These resistances are independent of Q and therefore they are included in M_i.

The expression for the power of the external resistances and of the additional internal resistances mentioned above has the form

$$N_1 = M_i\,\omega = \varphi_1 \frac{M_i Q}{D_y^3}.$$

Adding the power of all resistances we obtain

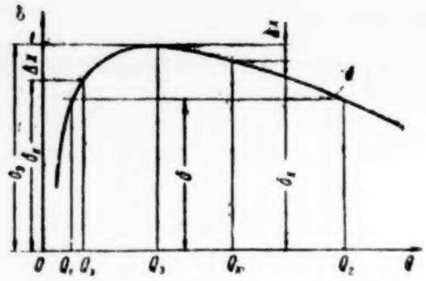

Fig. 2.

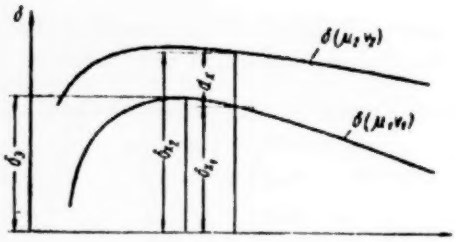

Fig. 3.

$$N_u = \frac{\Theta_A \mu Q^2}{(1-\psi_A) h D_y^2};$$

$$N_Q = \frac{1}{1-\psi_A}\left[\frac{\beta\mu^{0.2}\rho^{0.8}Q^{2.8}}{D_y^{3.8}} + \frac{\varphi_i M_i Q}{D_y^3}\right]$$

The leakage of the liquid through the clearances is determined by the expression

$$q = \left[\frac{hbC}{2} + \frac{bh^3\Theta_A}{12l(1-\psi_A)hD_y^2}\right]Q + \\ + \frac{bh^3}{12\mu l(1-\psi_A)}\left[\frac{\beta\mu^{0.2}\rho^{0.8}Q^{1.8}}{D_y^{3.8}} + \frac{\varphi_i M_i}{D_y^3}\right]. \quad (5)$$

The final expression for the determination of the percentage error will be of the form

$$\delta = \delta_0 - \delta_Q = \delta_0 - \frac{k}{\mu}\left[\frac{\beta\mu^{0.2}\rho^{0.8}Q^{0.8}}{D_y^{3.8}} + \frac{p_0}{Q}\right] = \\ = \delta_0 - k\left[\frac{\beta Q^{0.8}}{\nu^{0.8}D_y^{3.8}} + \frac{p_0}{\mu Q}\right], \quad (6)$$

where

$$\delta_0 = \left[\left(\frac{A}{Wt} - 1\right) - \frac{bhC}{Wt} - \frac{bh^3 A\Theta_A}{12lWt(1-\psi_A)hD_y^2}\right]100, \quad (7)$$

$$k = \frac{bh^3 A \cdot 100}{12lWt(1-\psi_A)}. \quad (8)$$

Here

$$p_0 = \frac{\varphi_i M_i}{D_y^3}, \quad (9)$$

$\underline{\nu}$ is kinematic viscosity; C is numerical coefficient.

For the determination of the error of the flowmeter, by means of (6), when the flowmeter is used for measuring the flow of a liquid of given parameters $\underline{\nu}$ and μ one must know the values of p_0, β, $\underline{k}$ and δ_0.

The value of p_0 of a given flowmeter can be determined experimentally. To do this, one has to measure the pressure difference of the liquid between the inlet and outlet nozzles at gradually reduced flow rates at the moment when the working part of the meter is being stopped. These measurements must be repeated several times and at various positions or the working part, and an average value should be computed. When a new flowmeter is designed, the value p_0 is fixed according to analogy with existing meters of a given type, and the internal loads due to recording and other mechanisms driven by the meter shaft are taken into account.

The value β is a numerical coefficient which defines the type (family) of meters in which the dimensions and the design of working parts are hydraulically and mechanically similar. Experience has shown that the value β can be assumed to be constant for various liquids for a given flowmeter type.

The expression for determining β can be obtained by equating the derivative $d\delta/dQ$ to zero. From (6), we obtain

$$\beta = \frac{p_0 \nu^{0.8} D_y^{3.8}}{\mu Q_e^{1.8} \cdot 0.8}. \quad (10)$$

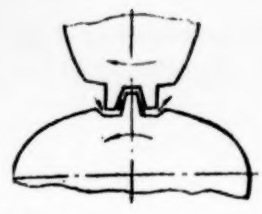

Fig. 4.

The discharge Q_e corresponding to the maximum percentage error, can be determined directly from the experimental error curve for the given meter.

The value β can be determined in yet another way. One can find such a value δ on the experimental error curve, which would have two corresponding values of discharge of which $Q_1 < Q_e$ and $Q_2 > Q_e$ (Fig. 2).

On the basis of the above condition we can write:

$$\frac{\beta Q^{0.8}}{\nu^{0.8} D_y^{3.8}} + \frac{p_0}{\mu Q_1} = \frac{\beta Q_2^{0.8}}{\nu^{0.8} D_y^{3.8}} + \frac{p_0}{\mu Q_2},$$

and, hence, we obtain

$$\beta = \frac{p_0 \nu^{0.8} D_y^{3.8}\left(\frac{1}{Q_1} - \frac{1}{Q_2}\right)}{\mu (Q_2^{0.8} - Q^{0.8})}. \tag{11}$$

Equating (10) and (11), we obtain

$$Q_e^{1.8} = \frac{1.25 (Q_2^{0.8} - Q_1^{0.8})}{\left(\frac{1}{Q_1} - \frac{1}{Q_2}\right)}. \tag{12}$$

Expression (12) can be used for a more accurate definition of the value of Q_e when it cannot be determined with adequate accuracy directly from the experimental error curve.

If the value β for a given type of the flowmeter is known, the value p_0 can be determined from (10) or (11) by substituting the corresponding values of Q_1, Q_2 or Q_e obtained directly from the experimental curve.

The value $\underline{k}$ can be determined from (8) by substituting the corresponding dimensions of the flowmeter and assuming $\psi_A = 0.1–0.15$. However, the determination of the actual value of bh^3/l presents considerable practical difficulties, since even a small error in the determination of $\underline{h}$ has a significant effect on the value $\underline{k}$. Therefore, the determination of $\underline{k}$ from (8) can be recommended only for preliminary calculations; the determination of the value $\underline{k}$ of the flowmeter in operation must be carried out directly with the use of the experimental error curve.

From the plot (Fig. 2) it is seen that

$$\Delta x = \delta_e - \delta_x = k\left[\frac{\beta}{D_y^{3.8} \nu^{0.8}} (Q_x^{0.8} - Q_e^{0.8}) + \frac{p_0}{\mu}\left(\frac{1}{Q_x} - \frac{1}{Q_e}\right)\right].$$

Substituting β from (10) we obtain

$$k = \frac{\Delta x}{\frac{p_0}{\mu Q_e}\left[1{,}25\left(\frac{Q_x^{0.8}}{Q_e^{0.8}} - 1\right) + \left(\frac{Q_e}{Q_x} - 1\right)\right]}. \tag{13}$$

By determining Δx directly from the graph, using (13) one can calculate the value $\underline{k}$ or $kp_0/\mu Q_e$.

The value δ_0 can be determined in the following way.

Substituting the value β from (10) in (6), we obtain

$$\delta = \delta_0 - \frac{kp_0}{\mu Q_e}\left[\frac{Q_x^{0.8}}{Q_e^{0.8} \cdot 1{,}25} + \frac{Q_e}{Q_x}\right].$$

For $Q_x = Q_e$, we obtain

$$\delta_e = \delta_0 - \frac{kp_0 \cdot 2{,}25}{\mu Q_e}.$$

Upon obtaining the value of δ_e from the experimental graph and knowing $kp_0/\mu Q_e$, we determine δ_0.

With the use of the formulae derived above and using experimental results from the measurements of the liquid of μ_1 and ν_1 with the flowmeter one can plot the error curves for a given meter for any other liquid of different μ and $\underline{\nu}$.

It is seen from Fig. 3 that

$$\alpha_x = \delta x_2 \quad \delta x_1 = \frac{kp_0}{\mu_1 Q_e}\left[1.25\frac{Q_x^{0.8}}{Q_e^{0.8}}\left(1-\frac{\nu_1^{0.8}}{\nu^{0.8}}\right)+\frac{Q_e}{Q_x}\left(1-\frac{\mu_1}{\mu}\right)\right]. \tag{14}$$

Upon determining Q_e directly from the experimental curve and calculating $kp_0/\mu_1 Q_e$ from (13) one can, using (14), determine α_x for various discharge rates and for any values of μ and $\underline{\nu}$ and, hence, plot corresponding curves of the variation of the experimental error δ.

As a result of a comparison, it has been established that the theoretical formulae which provide a definite quantative relationship between the error of the meter and the main factors, are in good agreement with the experimental data for various types and dimensions of flowmeters employed for various liquids and under various conditions.

In the course of the investigations, it was established that the results of the test on some specimens of flowmeters with oval wheels did not coincide with the theoretical results. The experimental error curve for these meters lies considerably above the theoretical one for small discharge rates, but, beginning from a discharge rate somewhat below Q_e (this being for tests with water) and up to a maximum discharge rate, we find that both these curves coincide. A detailed study of those meters showed that this particular feature is typical for meters which have considerable clearances between the working contour of the teeth of the working wheels. The relationship between the leakage through these clearances and the discharge rate is quite distinct from the relationship between the leakage and the discharge rate through the remaining clearances. This is explained by the fact that the liquid between the clearances between the toothed wheels flows in the opposite direction to the motion of the teeth of the working wheels (Fig. 4).

At a low speed of the teeth, the liquid flows through the clearances between the working surfaces. As the speed of the wheels(the discharge rate) increases the leakage between the toothed wheels decreases and with a further increase in the speed it ceases completely.

The effect of the leakage through the clearances in the toothed wheels on the error of the meter can be determined in the following way. From the experimental curve and from (13) one determines the value $kp_0/\mu Q_e$ for the maximum discharge rate. By substituting the obtained value $kp_0/\mu Q_e$ into (13), one can determine the values of Δx for various discharge rates Q_x and, hence, plot the calibration curve for the meter error. The difference between the ordinates of the theoretical and experimental curves represent that part of the flowmeter error at a given Q, which is due to the leakage of the liquid through the clearances between the wheel teeth.

It can be assumed that at a small discharge rate the error of the meter is determined by the value $kp_0/\mu Q$– c.f (6)– and, therefore, for a given Q this value is inversely proportional to the viscosity of the liquid measured.

Figure 5 contains theoretical curves for the error of a meter with oval working wheels of D_y = 40 mm made by the "Lengazapparat" Works; the curves were plotted from the experimental results obtained by the All-Union Scientific Research Institute. The continuous lines represent the theoretical (calculated) curves in which the error due to the leakage through the clearances between the teeth was taken into account. The points represent experimental results. The dynamic viscosity is given in poises and the kinematic in stokes.

By comparing (6) with (2), it is easy to establish that by neglecting the difference in the power (0.75 and 0.8), expression (6) can be obtained from (2) by means of the following rearrangements:

$$C_1=\delta_0;\ k''=\frac{\beta}{\nu^{0.8}D_y^{3.8}}=\frac{p_0}{\mu Q_e^{1.8}\cdot 0.8},\ k_0''=\frac{p_0}{\mu};\ C_2=\frac{k\beta}{\nu^{0.8}D_y^{3.8}}=\frac{kp_0}{\mu Q_e^{1.8}\cdot 0.8}.\qquad \lambda=\frac{p_0\nu^{0.8}D_y^{3.8}}{\mu\beta}=Q_e^{1.8}\cdot 0.8. \tag{15}$$

This shows that (2), obtained by A. I. Petrov, is practically identical with (6) given above, but (3) are found to be at variance with (15) and are incorrect since they are determined on the assumption that the values k'', k_0'', C_2 and δ are functions of μ only.

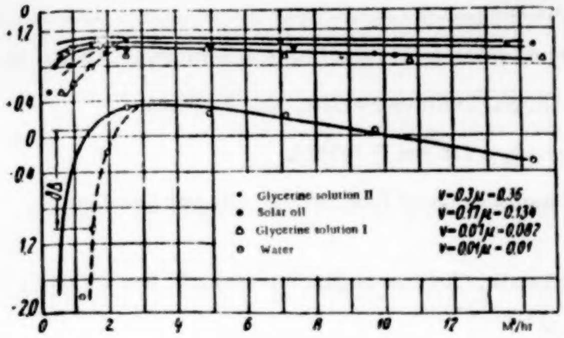

Fig. 5.

As a result of the investigation by V. V. Nikolaev [6, 7], who reported the results of a study of the leakage of liquid through the clearance between the walls of the measuring chamber and the working part, the following empirical expression was obtained:

$$\frac{q}{q_0} = \left(\frac{v_0}{v}\right)^{\frac{s}{1-s}}, \tag{16}$$

where q_0 is the leakage determined experimentally for the meter measuring liquid of a kinematic viscosity v_0; $\underline{q}$ is the leakage for the same flowmeter measuring liquid of the viscosity $\underline{v}$ at the same temperature; $\underline{s}$ is a coefficient, constant for meters of all types and equal to $0.49/n^{0.098}$; $\underline{n}$ is a number of revolutions or cycles of the moving part.

While studying the operation of a liquid flowmeter by using the methods based on the theory of similarity, V. V. Nikolaev assumed incorrect conditions for the solution of the problem and, hence, obtained results with which we cannot agree.

Assuming that the leakage of the liquid through the clearances between the working part and the walls of the measuring chamber is determined mainly by the speed of the rotating part, V. V. Nikolaev did not take the effect of the pressure drop between the inlet and outlet of the gap on the leakage into account in his investigations. In addition, it was assumed in his investigation that the leakage depends only on $\underline{v}$ of the liquid.

From (16), one can deduce that for a given value of $\underline{n}$ the following equality for any value of $\underline{v}$ is valid:

$$q_1 \nu_1^{\frac{s}{1-s}} = q_2 \nu_2^{\frac{s}{1-s}} = \text{const.} \tag{17}$$

It is indicated in (6) that for liquids of $v > 4\ \text{cm}^2/\text{sec.}$ the leakage of the liquid through the clearance is practically equal to zero. From this indication one can assume that by "the leakage" V. V. Nikolaev means only that part of the leakage which depends on the parameters of the liquid measured, but completely ignores that part of the leakage which depends on the dimensions of the meter and which varies linearly with $\underline{n}$ and Q (see (5)).

In the given, according to (5), the part of the leakage under consideration can be expressed in the form of the sum in which the first term is $k\beta Q^{0.8}/v^{0.8}\,D_y^{3.8}$ and the second is kp_0/μ.

It follows from the above that (17) can take place only at $\frac{S}{1-S} = 0.8$ and constitutes a constant, independent of $\underline{n}$ or Q.

Actually, the value kp_0/μ is always greater than zero and has a considerable effect on the leakage and the error of the flowmeter readings, in particular at small and medium discharge rates. Therefore, the relation between $\underline{s}$ and $\underline{n}$ was artifically introduced in (16) in order to take into account the effect of $kp_0/\mu > 0$ on the leakage expressed in terms of the kinematic viscosity.

The value p_0 is not constant and depends on the type, dimensions and design of the tramsmission system between the working part and the pointer, on the condition of the flowmeter, etc.

In addition, for one and the same value of $\underline{v}$, the value of μ of the liquid can be of various magnitudes. Hence, the value $\underline{s}$ should depend not only on $\underline{n}$ but also on p_0/μ and $\beta/D_y^{3.8}$. Consequently, the value $\underline{s}$ introduced in (16) can, at best, be accepted only as a particular one and arbitrarily suitable for some quite specific value of p_0/μ and $\beta/D_y^{3.8}$ representing the actual dependence of the leakage on the discharge with a certain accuracy.

The author tested (16) experimentally, using the indicated value of $\underline{s}$; the test did not give positive results and provided yet another confirmation of the fact that the leakage and the readings of the liquid flowmeter depend not only on the kinematic viscosity $\underline{v}$, but also on the dynamic viscosity μ of the liquid and on the pressure difference p_0.

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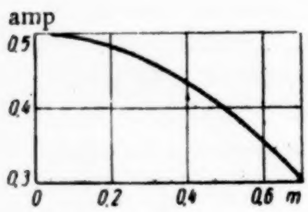
ON THE PROBLEM OF THE DESIGN OF FLOWMETERS

S. S. Kivilis

Specifications 27-54, relating to the application and testing of flowmeters with normal orifices, nozzles and venturi meters, envisage a graphical and analytical method of design calculations for reduced-area flowmeters, which in most cases ensures sufficient accuracy: if one calculates the diameter of the orifice of the meter and, hence, determines the flow rate corresponding to the maximum pressure difference of the differential manometer, the deviation in the value of the flow rate from the maximum reading on the scale (diagram) is not more than ± 0.2%.



Sometimes, however, it is not possible to attain such an accuracy and it becomes necessary to introduce appropriate corrections to the calculated diameter of the orifice. Let us consider the method of determining this correction.

With Reynolds Numbers above the critical value, the discharge coefficient of the meter is a function of only one factor:

$$m = \frac{d^2}{D^2}, \tag{1}$$

where d is the diameter of the orifice; D is the internal diameter of the pipe.

Then, for very small changes of the orifice diameter d and for D = constant, the relationship between the discharge Q and the diameter d can be written as

$$Q = C\alpha_u d^2, \tag{2}$$

where C is a constant factor; α_u is the initial discharge coefficient.

In (2), the effect of small changes of d on the correction factors, which represent the expansion ϵ of the medium measured, the roughness k_2 of the pipe, K_3 and the sharpness of the edge of the orifice, is not taken into account as it is negligibly small.

Let us find the derivative of the function (2);

$$\frac{dQ}{d(d)} = \frac{\partial Q}{\partial \alpha_u} \cdot \frac{d\alpha_u}{dm} \cdot \frac{dm}{d(d)} + \frac{\partial Q}{\partial d}. \tag{3}$$

m	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.65	0.7
a	0.50	0.49	0.48	0.46	0.43	0.40	0.36	0.33	0.31

After differentiating and separating (3) termwise for Q and taking (1) into account we obtain

$$\frac{dQ}{Q}=\left(\frac{C\,d^2}{C\alpha_u\,d^2}\cdot\frac{d\alpha_u}{dm}\cdot\frac{2d}{D^2}+\frac{2\,C\alpha_u\,d}{C\alpha_u\,d^2}\right)d\,(d);$$

By multiplying the first term in brackets by d/d then simplifying and substituting m for the ratio d^2/D^2 we find

$$\frac{dQ}{Q}=2\left(\frac{m}{\alpha_u}\;\frac{d\alpha_u}{dm}+1\right)\frac{d\,(d)}{d}$$

or

$$\delta_Q=2\left(1+\frac{m}{\alpha_u}\cdot\frac{d\alpha_u}{dm}\right)\delta_d, \tag{4}$$

where

$$\delta_Q=\frac{dQ}{Q}\ \text{and}\ \delta_d=\frac{d\,(d)}{d}.$$

are the changes of the discharge and of the orifice diameter of the flowmeter respectively.

Introducing the notation

$$a=\frac{0.5}{1+\frac{m}{\alpha_u}\cdot\frac{d\alpha_u}{dm}}, \tag{5}$$

from (4), we finally obtain

$$\delta_d=a\,\delta_Q. \tag{6}$$

The values of $d\alpha_u/dm$ for various m are easily determined by the graphical differentiation of the function $a_u = f\,(m)$ for orifices and nozzles (see Figs. 19 and 20, specifications 27-54).

The values of the factor a, calculated from (5), for orifices and nozzles for the same m were found to be in agreement within the limits of 0.01-0.02 and, hence, mean values could be determined. The mean values of a for orifices, nozzles and venturimeters are shown in the table from which a graph was plotted. By means of Eq. (6) in combination with the graph, one can rapidly determine the correction δ_d (%) for the orifice diameter of the meter; the introduction of the correction results in a change in the discharge by δ_Q (%). If the discharge, calculated for a given value of d, exceeds the accepted upper limit of the readings on the scale (diagram) of the differential manometer, the correction δ_d is given the sign "minus," otherwise it is given the sign "plus."

Example. The upper limit of the reading on the scale of the instrument Q_{sc} = 12,500 kg/hr. Calculated value: m = 0.2. Calculated value of the orifice diameter: d = 85 mm; corresponding discharge: Q = 12,465 kg/hr. i.e., δ_Q = 0.3%.

From the graph: for m = 0.2 we have a = 0.48, and, hence, according to (6) $\delta_d = 0.48 \cdot 0.3 = 0.15\%$.

Since $Q < Q_{scale}$, the correction is positive, i.e., the required orifice diameter will be

$$d=88.85+88.85\cdot0.0015=89.0\ \text{mm}.$$

The calculation shows that for d = 89 mm the calculated discharge rate is Q' = 12,500 kg/hr., i.e., $Q' = Q_{sc}$.

If one follows the specifications mentioned above with respect to the allowable deviation (± 0.2%) of the

calculated discharge rate from the given value in industrial measurements, then the method of determining the correction is simplified further; independently of the value of m, the correction is calculated by means of an average factor, $a_{av} = 0.4$ (see graph).

Equation (6) can also be very useful for the determination of the optimum tolerance in the diameter of the orifice of the flowmeter depending on the required accuracy in the discharge rate measurement.

ESSAYS AND REVIEWS

MODERN TECHNOLOGY OF ELECTRICITY METERS

A. M. Iliukovich

Modern electricity meters are efficient measuring instruments, yet their further development is proceeding at a considerable rate both with respect to the improvement of existing types and designing new ones for general and special purposes.

Special meters such as multi-rate, loss, peak load, slot, maximum load indicator, integrating meters, etc., are widely used abroad. It is interesting to note that Landis and Gyr (Switzerland) make over 20 types of such meters. At present many new types of meters of this kind are being produced [2-7]. Of special interest among them are the meters made by the AEG (FGR) [8-11] designed to measure electrical energy at large power stations by means of pulse recording. The meter readings are converted into pulses whose number is proportional to the recorded energy. These pulses are fed to a recording instrument which is designed to record simultaneously four meters and can be placed at distance of 20 km away from them. For each pulse of an originating meter a hole is punched on the registering instrument paper tape which moves at a constant speed. The results thus obtained are worked out by means of a quick-operating instrument which deciphers automatically the results and performs all the required calculations. By means of this instrument it is possible to obtain any of the required characteristics of electrical consumption such as the number and size of maximum loads, mean consumption over a given period of times, etc.

Attempts to introduce new systems of rating domestic consumers [12] are also interesting. It is proposed to charge an extra rate if the consumed power exceeds a fixed maximum. For this purpose miniature bimetallic indicators, placed under the elongated cover of the terminal board of the single phase meter and indicating the number of times the maximum power was exceeded, are used.

Special purpose meters are not used in our country, although the desirability of having such meters as double rate, maximum load indicating and other meters,is obvious.

One of the basic tendencies in designing modern meters is to make them robust so as reduce maintenance costs connected with periodic checking and repair of these instruments.

In the majority of countries the period of checking single phase meters is equal to 8 years and in Switzerland it has been raised to 14 years. At present the largest firms such as AEG and Siemens (FGR), Westinghouse and the General Electric Co. (USA), Candian General Electric (Canada) and others, are producing electricity meters with a life without repairs of 20-30 years [13-18].

The production of such meters required the solution of several complicated technical problems, primarily in that of obtaining the durability of the moving part bearings. A radical solution of this problem was found by the General Electric Co. which employs magnetic suspension of the moving part [19]. At present this method is fairly widely used [20-22], especially in dc and mutliphase meters which have fairly heavy moving parts. Other firms have found different methods of making durable bearings. In particular the AEG and Siemens use the so-called double jewel bearings [23] for their long life electricity meters. Its construction and that of a normal bearing are shown in Fig. 1. Such a bearing without librication ensures very small friction which hardly changes with time.

In long-life-electricity meters no lubrication of moving parts is used. This avoids the possibility of a variation in friction due to dirt accumulation or clogging in the oil. In order to avoid the possibility of corrosion the ball of the lower bearing, the needle of the upper bearing and the axle of the counting mechanism are made of stainless steel.

In the long-life electricity meters both pointer and roller type registers are used. The former is usual for American and British firms and the latter for German and many European firms.

In the new designs of roller type registers the diameter of roller axles has been reduced to 0.6 mm from the former 1-1.2 mm. The bearings which support these axles are made of polyamide or polyurethan. All the gears of the counting mechanism are made of these materials since they have a small friction coefficient, low specific gravity and a considerable stability under all climatic conditions. These measures reduced friction to 1/10 of its former value making it equal to 0.5-1 mg·cm. Variation of this friction even by a factor of 2, which is unlikely, cannot alter the accuracy of the meter even at the lowest specified value (5% of the nominal) by more than 0.5-0.7%.

Just as important, though not so difficult, is the problem of obtaining sufficiently stable brake magnets. The overwhelming majority of foreign firms make the brake magnets of highly retentive alloys of the alnico type.

The construction of long-life meters also required hermetic sealing of the container, the use of sufficiently reliable anti-corrosion materials and coating, increased resistance to short circuits, protection against excessive voltages, increased reliability of sealing, and improved terminal connections.

Long-life meters usually have complete temperature compensation, i.e., they are temperature compensated not only at $\cos\varphi = 1$ as usual, but also at $\cos\varphi = 0.5$. This compensation is increasingly used in ordinary meters [24, 25] which are not designed for long life.

Many long-life meters are designed for a wide voltage range, for instance, from 50 to 130% of the nominal [26, 27] instead of the nominal voltage only. This is done in order to meet the requirements which may prevail in 20 to 30 years' time at the end of their life. During this time the conditions of work of the meters can change, such as for instance the voltage of the supply, the nominal loading of the meter, etc. In order to avoid changing meters due to changed requirements long before the end of their life, the meters are made for two nominal voltages, their temperature range is increased, their overloading limits enlarged etc.

Long-life meters are made with an overloading capacity of 400-700% of the nominal value. Thus Metropolitan Vickers (Britain) NF-5 and Siemens W2O4 single phase meters have an overload point of 500%, the three-phase AEG type C31U meter and the three-phase Westinghouse two-element meter, an overload capacity of 600%, the single-phase General Electric Co. type I-60 meter, an overload of 667%. Meters with an overload capacity of 400% which only a few years ago were considered as a great achievement are now produced by the majority of firms.

The high overload capacity is attained by a rational choice of design parameters of the measuring mechanism with the object of obtaining a high quality-factor for the driving element [31], a decrease in the nominal speed of rotation (down to 8-15 rpm) and by magnetic shunting of the driving element series circuit.

The theoretical problems connected with raising the overload capacity of meters have been widely investigated and the manufacture of meters with high overload capacities does not encounter any theoretical difficulties. Experimental samples of single phase meters were made with an overload capacity of 2000% of the nominal load [28] which considerably exceeds the present day practical requirements.

Important work is also being conducted in our country on the improvement of the existing and on development of new, more efficient designs of meters. Improvement of the basic metrological characteristics of electricity meters can be seen from Fig. 2 where load characteristics of single-phase meters type SO-1, SO-2 and SO-42 are shown. The construction of the driving elements of these meters is shown in Fig. 3.

Meter SO-1 and its predecessor SO had a very simple design, used cheap materials and were easy to manufacture. At the same time the design of these meters had a number of important defects and a low quality factor of about 80 g·cm/w·rps.

The design of meter SO-2 [30] whose production was started in 1956 improved considerably on the metrological qualities of our meters. The improvement was attained without changing the general design and the production procedures adopted; by a more rational selection of the parameters of the measuring mechanism, a decrease in the nominal speed of rotation of the moving part of the meter and by using better quality materials.

The main measure which led to the improvement of meter SO-2 was the introduction of "tangential" torque producing sectors (Fig. 3). For this purpose the nonoperative gaps in the core of the shunt circuit were placed in

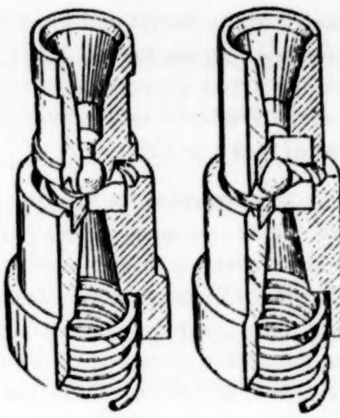


Fig. 1.

Fig. 2. 1) SO-1; 2) SO-2; 3) SO-42.

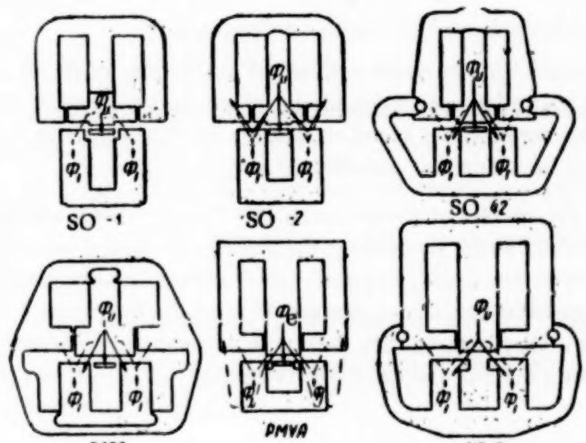


Fig. 3.

the middle of the butt ends of the series circuit cores, which led to the formation of an additional (tangential) component of the shunt circuit effective flux which crossed the disc twice. It is shown in [30, 31] that such a placing of the poles is the best for the case when there is no cross magnetization of the series circuit produced by the parallel circuit effective flux. The quality factor of the SO-2 meter reaches 200 g · cm/w · rps which ensures very favorable metrological characteristics without using magnetic shunting of the series circuit. The use of magnetic shunting could increase the overload capacity of the meter to 350-400% of the nominal load.

Some of the defects of the SO-2 meter consist of the excessive simplicity of certain units and details, especially of adjusting devices, the presence of a dip in the load characteristic at low load values and considerable second order defects (due to temperature, voltage, frequency, position) etc.

The electricity meter SO-42 developed by the Mytishchin electricity meter plant (with the participation of the author) which recently passed the state tests has none of the above defects and its overload capacity amounts to 400%. Its load characteristic in the small load region has also been improved as compared with the SO-2 meter. The nominal torque has been raised, the temperature variations fully compensated and the design of the adjusting devices and the terminal box improved.

A tendency for obtaining a high overload capacity with a small expenditure of electrical materials, small consumption, and, a sufficiently high torque by means of the largest possible rise in the quality factor was the guiding principle in the design of the SO-42 meter.

The meter has a driving element whose series circuit is also magnetized by the shunt circuit flux, the magnetizing poles being placed in the optimum positions for superposed magnetization so that the poles of the series and shunt circuits overlap each other.

In order to raise the quality factor of the driving element a pole strip made of structural sheet steel is attached to it, and although this increases the total lag in the circuit it also increases the meter quality factor by some 30-40% as the theoretical considerations and practical experience has shown.

Other driving element parameters such as the ratio of the effective to stray fluxes in the shunt circuit, the ratio of the thickness of the disc to the effective gap, the distance from the driving element to the center of the disc, the relation between the dimension of the central limb of the shunt circuit core and the volume of copper in the voltage coil, etc., were also chosen so as to obtain the maximum quality factor.

As the result of this, the quality factor of meter SO-42 is about 235 g · cm/w · rps. This has been attained with half the copper used in the voltage coil as compared with meter SO-2. The nominal speed of rotation of the meter is 16.5 rpm, the consumption of the shunt circuit is 1.1 w and the torque is 4.8 g · cm.

In order to be able to compare the basic ideas embodied in the design of the Soviet and some of the foreign meters, scale sketches of the driving elements of some of the modern meters are given in Fig. 3, they include meter NF-5, Chamberlain and Hookham (Britain) meter type PMVA, and the Krizik (Czechoslovakia) meter EJE8. The metrological characteristics of these meters are about the same, meter NF-5 has a rather higher overload capacity of 500%. The overload capacity of meter EJE8 is 400% and that of PMVA is 300%.

In meter NF-5 there is no joint in the main shunt circuit flux path. This improves the uniformity of characteristics of different meters, but complicates the assembly of the shunt circuit and opposes an effective choice of the driving element parameters for a maximum quality factor. In order to obtain a large torque it is necessary to have sufficiently large poles in the shunt circuit, i.e., the width of the central voltage core must be large. This, however, produces a considerable increase in the mean diameter of the voltage coil and in its resistance, and hence in the consumption of the shunt circuit. A greater freedom in the effective choice of the shunt circuit parameters is provided by a system with a detachable shunt circuit core (SO-2, SO-42 and EJE8), but such a system worsens the consistency of characteristics.

Meter NF-5 has no pole strips. It is also peculiar in having a large effective air gap (3.6 mm against 2.4 mm in meters SO-1, SO-2 and SO-42) in the driving element. This makes the readings of the meter less dependent on frequency and has a good effect on the loading characteristic in the region of small loads [32] but has a negative effective on the quality factor of the meter. The latter is for the NF-5 meter equal to 115 g · cm/ w · rps, i.e., it is very small.

Thus the main criterion in designing meter NF-5 was the maximum stability of the measuring mechanism.

The high overload capacity of meter NF-5 has been attained owing to a small torque (4 g · cm) a large consumption in the shunt circuit (1.6 w) a small nominal speed of rotation (16 rpm) and a rational choice of the series circuit magnetic shunt.

The driving element of the PMVA meter has a pole strip. This provides with small dimensions of the driving element a sufficiently high value of the quality factor (175 g · cm/ w · rps). The torque of the PMVA meter is 4.7 g · cm the consumption of the shunt circuit is 0.85 w, and the nominal speed of rotation is 27.5 rpm. The dimensions of the driving element and hence the expenditure on electrical materials is very small.

This design can be regarded as intermediate between the meters of Soviet make (SO-2, and SO-42) which aim at attaining the maximum quality factor and meter NF-5 in which everything is subordinated to the stability of the measuring mechanism. American meters resemble meter NF-5 with respect to their measuring mechanisms; whereas meters SO-2 and SO-42 are akin in their basic design ideas to German meters (W1a of the Electrical Instrument plant in Berlin, W9 of Siemens, etc.) which have a very high quality factor. It is possible to name a number of designs which occupy an intermediate position, they include the Remco I-11 (India) the meters of the Companie de Compteurs (France) and others.

Such a design is followed in meter EJE8. In the design of this meter certain steps were taken to increase its quality factor (it has a pole strip, the reluctance to the main flux of the shunt circuit has been reduced to the minimum at the junction of the central arms with the core, etc),on the other hand certain steps were also taken for raising the stability of the driving element (it consists of a closed magnetic circuit with the core of the series circuit and the central limb of the shunt circuit impressed into it). The peculiarity of the EJE8 meters consists in their small voltage coil which provides a larger space between the coil and the disc thus making room for devices controlling the compensation torque and internal slip.

The equality factor of the EJE8 meter is small amounting to 120 g · cm/ w · rps the torque is equal to 5.3 g · cm, the consumption of the shunt circuit is 0.85 w and the nominal speed of rotation 18.3 rpm. The error compensated by means of the magnetic shunt is large.

There also exist of course,designs which do not incorporate any of the above mentioned tendencies in the choice of the parameters of their measuring mechanisms. In many instances the designs reflect various patent considerations.

In concluding the review of modern improvements in the design of electricity meters it should be noted that the Soviet electricity meter plants will have to solve,in the near future,yet other important problems. Among these problems are the improvement of the metrological characteristics and increased life in the electricity meters produced.

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MODERN HIGH PRECISION BRIDGES FOR MEASURING INDUCTANCE AND CAPACITANCE AT AUDIO FREQUENCIES

E. S. Livshits

Recent achievement in the design of ac bridges have not been reflected either in books [1] or in the periodic literature (see also [2]).

The present review partly fills this gap with respect to one group of instruments, namely bridges for measuring capacitances and inductances at audio frequencies, which have now attained a higher degree of precision than similar bridges in other frequency ranges.

The present review is based in the main on descriptions of instruments pamphlets and technical bulletins of instrument making firms, A. Wirk and H. G. Thilo's book [3] which contains in its descriptive part only the materials supplied by the firms and other sources (unpublished materials of the author, etc).

We shall call "high precision" bridges those which have an error not exceeding 0.5%; bridges with a higher permissible error should be classified as universal bridges, although this group already contains bridges with a permissible error of 0.5% (type TF-936 of the Marconi Instruments). We also include in the precision group the multi-range bridges whose permissible error in some parts of a range (for instance at the limits) exceeds 0.5%, since such deviations are, as a rule, legitimate and peculiar to many instruments.

Bridges designed to measure capacitances and loss angles at a loss (supply) frequency only, and at a high voltage (Schering bridges and others) constitute a special group mostly used for checking the state of certain components and are not dealt with in this review.

I. Induction Bridges. Commercial type induction bridges are usually based on circuits which compare the unknown inductance with a known capacitance or inductance.

One of the circuits of this group, the Maxwell – Wien bridge circuit, was mostly used up to 1940. Since then, owing to considerable improvements in inductance boxes, one of the circuits of the second group (Maxwell's bridge) also became popular after having been used in the past without great success.

TM-382 type bridge. (Tesla, Czechoslovakia). This bridge has an inductance range from 1 μh to 1 h; permissible error of ± 0.2% of the reading or ± 0.2 μh (whichever is the larger) up to 0.1 h and in the remaining range ± 0.5%. Its frequency range is 100 cps to 10 kc.

The TM-382 bridge is based on the above-mentioned Maxwell-Wien circuit in which the inductance is compared with a fixed capacitance in the opposite arm of the bridge and a noninductive resistance which shunts the capacitance; the other two arms are nonreactive, one of them is continuously variable and serves to make the measurement. The balancing is done in above arm and in the capacitance arms with the shunting resistor, i.e., in two different arms of the bridge, which leads to a flat balance when the Q of the measured inductance is lower than 2. High-frequency coils for instance, measured at audio frequencies will have such a low Q factor. The

TM-382 and similar bridges with ranges extending down to microhenries or fractions of a microhenry will encounter such difficulties. Flat balancing leads to the so-called "sliding minimum" [4].

667-A type bridge (General Radio Co. USA) is similar to the above in its general technical characteristics: measuring range 0.1 μh to 1 h (it can be extended by connecting external induction coils); its error of measurement is $\pm$ 0.2% of the reading or $\pm$ 0.1 μh (whichever is the larger) up to 0.1 h and $\pm$ 0.4% in the range from 0.1 to 1 h. This bridge is designed to work mainly at 1 kc and is based on Maxwell's circuit, the inductance under test being compared with a known (standard) inductance placed in the adjacent arm, the remaining two arms being nonreactive and one of them variable and used for measurement. If in this bridge the inductance were to remain constant and the measurement to be carried out by one element only, the balancing conditions of the circuit would be exactly the same as those for bridge TM-382. This was precisely the case with Maxwell type bridges manufactured some 30 years ago (for instance the bridge previously produced by Siemens and Halske).

In this bridge, however, an improved Maxwell circuit is used; the arm with the unknown has a variable calibrated inductance incorporated in the bridge, connected in series with the unknown for the purpose of final balancing which eliminates the sliding minimum effect. However, this improvement is only effective with small inductances since the whole range of the variable inductance amounts to 10 μh only. This bridge is not very useful for measuring large inductances even with a fairly large Q, from the point of view of complex balancing, and in this respect it is even worse than bridge TM-382 and the obsolete Siemens Halske bridge mentioned before. This is due to the low Q of the bridge circuit standard coil which is small and toroidal. Since the bridge cannot be balanced unless the inductances placed in the two arms have the same Q factors, the Q of the inductance under test has to be artificially lowered by connecting in series with it a resistance which is incorporated in the bridge and adjusted until the two Qs are the same.

In other bridges based on the same principle, for instance, in the before-mentioned Siemens Halske bridge the standard inductance is connected externally. For this purpose normal "standard induction coils" are used whose Q factor even at a low frequency of 100 cps amounts to 3. The balancing in such bridges, with a Q of the inductance under test similar to the one mentioned above, is more satisfactory.

Siemens Halske bridge type Rel-3R-114. With adjustments similar to the one used in bridge TM-382 the settings of the inductance (L) and the resistance (R) are interdependent which leads to flat balancing when the Q of the inductance under test is low; if instead of the fixed capacitance a variable one is used, for instance a capacitance box, or variable capacitor in parallel with the variable resistance, on balancing, the two components becomes independent of each other and the balancing becomes sharp, irrespective of the Q of the inductance under test. Although bridges of this type were made in the past they were defective with respect to the range of measurement, accuracy, and ease of reading; and this version of the Maxwell-Wien circuit did not become popular. The modification of the Maxwell-Wien circuit adopted in the Rel-3R-114 bridge is therefore of interest.

This bridge has a considerably wider measuring range of larger inductances than either the Tesla or the General Radio bridges.

The table below shows the measuring error of the bridge (in percent) in the various measuring ranges and at different frequencies.

Thus, over a large part of the range the accuracy of this bridge is lower (1%) than that of the other two bridges, but it has a much larger range and a better balance than bridge TM-382 for low Q inductances. Independent balancing of the two components has been achieved in this bridge by the following modifications to the Maxwell-Wien circuit: the nonreactive arm which serves to measure inductance is made in the form of a single decade potentiometer, further division is attained by means of inductive dividers connected in cascade similar to the circuit of the "shunting decades" in certain dc potentiometers; the output of the complete divider is connected to a capacitance box (with 3 steps instead of the former one as in bridge TM-382); in addition the circuit includes a variable capacitor which is used for final balancing; various points of the above divider can be connected to three separate fixed resistances and one variable resistance which have one common terminal with the capacitor, and whose action is equivalent to a resistance shunting a capacitance in a conventional bridge circuit. As the result of this an almost completely independent balancing of the two components is obtained; only with very fine balancing does any interdependence of the components become apparent, when the balancing should be pursued until a complete balance is obtained.

Frequency range, cps	Measuring range								
	μh			mh			h		
	1–10	10–100	100–1000	1–10	10–100	100–1000	1–10	10–100	100–1000
50–200	—	—	—	—	—	—	0.3	1	2
200–500	—	—	—	0.3	0.3	0.3	0.3	1	2
500–2000	0.5	0.3	0.3	0.3	0.3	0.3	0.3	—	—
2000–5000	0.5	0.3	0.3	0.3	0.3	0.3	—	—	—
5000–20000	1	0.3	0.3	0.5	—	—	—	—	—
20–50 kc	2	1	1	—	—	—	—	—	—

In the Sullivan (Britain) AC 1100 type bridge the important defects of the previously described Maxwell type bridges, including the 667-A bridge, have been completely eliminated. It uses a variable inductance in the form of a high precision box (0.05%) instead of the fixed inductance. Since both adjustments are in the same arm of the bridge the circuit has an "ideal convergence" i.e., a perfect balance. The controlling technical characteristics of the bridge are: error of measurement ± 0.1% or ± 0.1 μh (whichever is the larger) in range of 1 μh to 10 h; or ± 1% in the range of 10 to 100 h; direct reading in the range of 50 to 3,000 cps,—with corrections the range can be extended to 12 and 20 kc (obviously in a narrower measuring range). With a substitution method of measurement the error can be reduced to 0.02%. With special attachments this bridge can also be used for measuring incremental inductance (up to 150 h) with an error of 0.5-1%, and for measuring capacitances from 10 μμf to 1 μf with an error of 0.2%. This it would appear is the most accurate bridge of its type.

II. Capacitance Bridges. In these bridges a perfect balance can be easily obtained. When capacitors are measured a perfect balance can always be obtained since any capacitor, with the exception of an electrolytic one, has a much higher Q than a coil. Many more bridges are made for measuring capacitance than inductance; however, the number of types which differ by their fundamental measuring properties and not by secondary characteristics or appearance is smaller than the number of types produced by various firms.

Of the various circuits used the most popular are Schering bridges and inductive ratio arms.

General Radio Co. bridges types 716-B and 716-C are based on the Schering circuit and have the following technical characteristics: direct reading capacitance range from 100 μμf to 1 μf in four ranges of ratios of 1, 10, 100 and 1,000, and by the substitution method from 0.1 to 1,000 μμf; the error of measurement is equal to ± 2 μμf × by a factor, which at the top end of each range amounts to ± 0.2%; their frequency range is 50 cps to 10 kc for the 716-B bridge and up to 100 kc for the 716-C bridge. The bridge measures the tangent of the loss angle at one frequency of 1 kc only, at other frequencies corrections must be applied; the loss angle tangent is measured from 0.00002 ($2\cdot10^{-5}$) to 0.56 with an error of ± 0.0005 or ± 2% of the reading (whichever is the larger).

Bridge type TM-351 (Tesla, Czechoslovakia) is similar to 716-B in its design and performance, the same as many other bridges made by various firms, which however specify in some instances a higher accuracy in the measurement of either the capacitance or the loss angle.

The BPL (Britain) type CB-161-A bridge is also similar to the 716-B bridge but the firm claims a greater accuracy in the measurement of capacitance, the error being ± 0.1% or ± 0.5 μμf.

Muirhead (Britain) type A-168-A bridge is also similar to the 716-B bridge but the firm specifies an error of ± 1 μμf × a range factor, which amounts to twice the accuracy of the 716-B type; the loss angle tangent has a error of ± 0.0003 or ± 3% of the reading.

"The precision capacity bridge" of the Cambridge Instrument Co. (Britain) has the same accuracy with respect to capacitance measurements as the preceding bridge, but its loss angle tangent measurements accuracy is greater amounting to ± 0.0002 or ± 2% of the reading.

The Sullivan "decade" and "precision decade" capacitance bridges should be classified separately. They are Schering bridges; their design is based on "air capacitor boxes" developed by this firm some 10 years ago and consisting of a combination of one or two decades of fixed air capacitors and one variable air capacitor; owing to their special construction these capacitor boxes are according to the firm's data very accurate both with respect to their capacitance and phase angle.

The "decade" bridge is made in three versions (types C-3040, C-2041, C-3042). We quote the data for type C-3042: measuring range from 1 μμf to 10 μf; error of measurement ± 0.1% in the range of 100 μμf to 10 μf and in the lower range i.e., at 1 μμf it is ± 0.03 μμf.

The frequency range has only a higher limit, thus at 10 μf the upper frequency limit is 2 kc, at 0.1 μf it is 40 kc, etc.

The bridge also measures the loss angle tangent of two-terminal capacitors with an error of ± 0.0001.

It should be noted that bridges of the C-3041 and C-3042 types are combinations of type C-3040 bridge with a one or a two decade capacitance box connected externally.

"The precision decade bridge" produced in four versions differs from the decade bridge by its accuracy. Version C-3023 is a combination of the C-3020 bridge proper and the accurate three-decade box C-1900 (up to 1 μf) and has a measuring range of 0.1 $\mu\mu f$ to 100 μf; the error in the middle of the range (0.1-1 μf) is ± 0.01% and it rises at the upper limit of the range to ± 0.1% and in the lower range it amount to ± 0.01 $\mu\mu f$. In the loss angle measurements this bridge is similar to the one previously described.

The Sullivan logarithmic capacitance bridge produced in versions, C-3000, C-3002 and C-3003, uses one reference logarithmic air condenser with a single scale. The technical characteristics of the bridge are: the main measuring range from 1 $\mu\mu f$ to 1.2 μf, which can be extended by means of attachment to 11 and 111 μf; error of measurement ± 0.2% in the range of 15 $\mu\mu f$ to 1 μf, ± 0.03 $\mu\mu f$ in the range below 15 $\mu\mu f$ and ± 0.3% in the upper range (up to 100 μf). The bridge measures at one frequency in the range of 800 to 2,000 cps, it does not measure loss angles.

Siemens Halske type Rel-3R-166 bridge with inductive ratio arms appears to be the most accurate of its type. Its total measuring range is from 0.001 $\mu\mu f$ to 100 μf (in 8 ranges); the mêasuring error at 800 cps is ± 0.1% in the range of 10 $\mu\mu f$ to 10 μf; ± 0.5% in the range of 0.1 to 10 $\mu\mu f$; ± 1% in the range of 0.001 to 0.1 $\mu\mu f$ and in the range of 10 to 100 μf. Its frequency range is 200 cps to 10,000 cps. The bridge also measures loss angle tangents to 0.1 (the variable range is to 0.02) and with direct reading at frequencies of 200, 800, 2,000 and 5,000 cps. The error of the loss angle tangent measurement at 800 cps is ± 5% of the reading ± 0.0005 in the capacitance range of 0.1 $\mu\mu f$ to 10 μf and at capacitance over 10 μf another 5% of the reading is added to the above error.

"Radiometer" (Denmark) bridge type CMB-1 is designed it would appear, on the basis of the same principle. The firm supplies the following data: measuring range from 0.001 $\mu\mu f$ to 1.111 μf, with an error of ± 0.1% above 10 μf, its frequency range is 200 cps to 5 kc.

Bridge type 204 of the RFT (GDR) plant is of the same type. It has the following characteristics: range from 0.01 $\mu\mu f$ to 1 μf, with an error of ± 0.2%, in the range of 100 $\mu\mu f$ to 0.1 μf, ± 0.5%, between 0.1 and 1 μf, ± 0.01, ± 0.05 and ± 0.2 $\mu\mu f$ in the ranges of 0.01-0.1, 0.1-1 and 1-100 $\mu\mu f$ respectively. The operating frequency (800 cps) is fixed by the oscillator built into the set complete with an amplifier which is connected to an external null indicator.

In comparing various bridges it will be seen that the highest accuracy is attained only when the best possible capacitance standard is either incorporated in the bridge or externally connected to it (Sullivan bridges type C-3020 to C-3023). Of the bridges which combine to the best advantage a wide range with accuracy and do not require any external attachments one should note the Siemens Halske bridge type Rel-3R-116.

III. Combined Bridges for Measuring Inductance and Capacitance. Rohde and Schwarz (FGR) type LCB bridge has the following characteristics: (taken from the catalogue) inductance range from 10 μh to 1,000 h, capacitance range from 0.001 to 1,000 μf, with an error of ± 0.3%. The inductance is measured in a Maxwell-Wien circuit and the capacitance in a Wien-Sauty circuit. The bridge is used in a range of 50 cps to 20 kc.

The "Universal impedance bridge" of the firm "ESI" (USA) type 290-R is designed to measure resistance, capacitance and inductance and has the following characteristics: inductance range up to 1,200 h in 7 ranges (the smallest division in the low range is 0.1 μh) with an error of ± 0.3% + 1 scale division, and at the lowest range of ± 0.4% + 1 scale division; capacitance range up to 1,200 μf in 7 ranges (with the smallest division of the lowest scale of 0.1 $\mu\mu f$) with an error of ± 0.2% + 1 scale division and at the top range ± 0.3% + 1 scale division. Its operating frequencies of 100, 400, 1,000 cps and 10 kc can be obtained from a pre-set frequency oscillator combined with a null indicator and supplied with the bridge.

Wayne Kerr (Britain) universal bridge type B-221 is designed as the preceding bridge to measure capacitance inductance and resistance. This bridge uses inductive ratio arms. Its operating frequency is fixed at 1592 cps. This frequency was chosen so as to give an angular velocity of $\omega = 10,000$. Its technical data is as follows:

capacitance range from 0.0002 $\mu\mu$f to 100,000 μf, inductance range from 0.005 μh to 10,000 h., with an error of ± 0.25%. The firm also indicates a number of operational advantages of the bridge.

SUMMARY

Bridges of the type of 716-B and TM-351 and in general Schering type bridges can be considered as most suitable for measuring capacitance. The wide use of such bridges permits one to consider them as "standard" for the purpose.

Attention should also be drawn to bridges with inductive ratio arms which possess very valuable properties: they require a small number of standard capacitors, they can measure the capacitance not only of two- but also of three-terminal capacitors, in this respect they are in no way inferior to the Schering circuit. Another property of these circuits should also be noted, they cannot be used at frequencies below 200 cps which rather limits their range of application as compared with some other circuit.

Soviet industry has not as yet progressed very far in making capacitance bridges. Manufacture of bridges similar to type 716-B and TM-351 has begun.

As far as the inductance bridges are concerned it is advisable to refrain, on the basis of the experience gained, from manufacturing bridges similar to TM-282 and completely reject the principle on which bridge 667-A is constructed, and which was criticized above. On the other hand improved types which are theoretically completely acceptable (such as the Sullivan AC-1100 or the Siemens Halske Rel-3R-114) will be too complicated for mass production. In addition the accuracy of the above-mentioned Siemens bridge may, despite many of its other advantages, prove to be in many cases inadequate.

The difficulties thus arising in the choice of an inductance bridge circuit may perhaps be resolved by M. A. Bykov's proposal [5] of using a modified Anderson circuit for direct reading measurements. This modification opens up great possibilities in measuring small inductances with small Q factors, which is the great difficulty in bridge design; yet the Anderson circuit which gives a perfect balance, can, with the proposed modification, provide convenient measurements up to 0.01 h. At higher values it is advisable to use a Maxwell circuit in its usual form, as for instance in the TM-382 bridge. Work in one of the development departments, according to available information, is being conducted on these lines.

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